Paramecium caudatum: The slipper Animalcule

Paramecium: introduction (YOUTUBE)

Protozoa which move with the help of cilia are called ciliates and are included in the subphylum Ciliophora. Besides the possession of these locomotor organelles, all ciliates possess two types of nuclei, macronucleus, and micronucleus (nuclear dimorphism), and a unique form of sexual reproduction (conjugation). Paramecium is a typical ciliate genus containing about 10 known species differing in shape, size, and structure. The largest species, *P. caudatum*, has a single comparatively large and compact micronucleus with chromatin material scattered throughout the nucleoplasm.
It occurs widely and abundantly. P. aurelia has two micronuclei while P. multi micronucleatum has many micronuclei. *P. bursaria* is green due to presence of symbiotic alga, zoochlorella. In the following text, the biology of *P. caudatum* is treated in detail.

Systematic position

Paramecium: systematic position (YOUTUBE)

Phylum	Protozoa
Subphylum	Ciliophora
Class	Cilliata
sub class	Holotricha
order	Hymenostomatida
sun order	Peniculina
Genus	*Paramecium*
Species	*Caudatum*

Occurrence

Paramecium caudatum (Gr., paramekes, Oblong +L. caudata, tail) is one of the most common species of paramecium having worldwide distribution. It is found in freshwater ponds, pools, pools, ditches, streams, rivers, lakes, reservoirs, etc. It is usually abundant in those waters which contain a great deal of decaying organic matter. It thrives well in ponds or slowly running streams containing aquatic plants. The paramecia often gather near the surface in scum, but are usually seen actively swimming throughout the water in which they live.

Culture of Paramecium

Paramecium is easily grown in wide mouthed jars with glass covers, three-quarter filled with boiled pond watt or Chalkey's medium (NaCI 80 mg. NaHCO3 4 mg. KO 4mg, CaCi2 4mg, Calla (P04)21120 1.6mg, dissolved one litre of distilled water), and with 7.12 drops d skim-milk added weekly. The jars are kept away direct light to allow bacteria to flourish which serve as food for the multiplying paramecia.

External Structure

[Paramecium: structure - external (YOUTUBE)]

1.Size. Paramecium is a microscopic, elongated organism which is visible to the naked eye as a whitish or greyish spot. Its species vary in length from 80M to 350 M. P. caudatum, the largest species, measures between 170u and 290 Mt. The greatest diameter of the cylindrical body is about two-third of its entire length. P. aurelia is about 120 k to 250 u long. Usually the individuals of the same spices may exhibit minor morphological and physiological differences. Jennings was able to find in one species of Paramecium eight races differing in total length and size.

2. Shape. Paramecium is often described as slipper shaped, cigar-shaped or spindle-shaped. Its shape is usually constant and in general asymmetrical. Because of its slipper-like shape, the Paramecium is sometimes called the slipper animalcule. Joblot assigned the name 'chausson' to P. caudatum which means slipper-shaped animalcule. The body is elongated, blunt and rounded at the anterior end and somewhat pointed at the posterior end. In cross section, it is circular with greatest diameter behind the center of body. The anterior half of body is slightly twisted. The body is distinguished into an oral or ventral surface and an aboral or dorsal surface.

3. Oral groove. Ventral surface of body bears a prominent, oblique and shallow depression, called oral groove. It originates from the middle of body and extends to the left side of anterior end. Posteriorly, the oral groove leads into a deeper conical vestibule which in turn communicates with a buccal cavity having a basal mouth or cytostome.

4. Pellicle. External envelope of body is a living, clear, firm and elastic cuticular membrane, the pellicle. When stained specimens are observed under light microscope, the pellicle appears to be a regular series of polygonal (or hexagonal) depressions with their raised rims. A single cilium emerges out from the middle of each polygon or circumciliary space. Electron microscopic studies by Ehret and Powers (1959) have revealed that the polygons are defined by a corresponding regular series of cavities, the alveoli. In fact, it is the pit in the Centre of each alveolus which forms a polygon. All the alveoli collectively form a continuous alveolar layer, which is delimited by an outer alveolar and inner alveolar membrane. The outer alveolar layer lies in close contact beneath the outer cell membrane (not shown in the diagram). Thus, the pellicle of Paramecium includes a series of three membranes: (i) outer cell membrane, (1) outer' alveolar membrane, and (is) inner alveolar membrane.

5. Cilia. The entire body surface is covered by numerous, tiny, hair-like fine projections, called cilia. These measure 10-12μ in length and 0.274 in diameter. As already stated, one cilium (2 in *P. bursaria*) arises from the Centre of each polygonal depression (circumciliary space) of * pellicle. There are 10,000 to 14,000 cilia covering the whole-body surface. These motile. organelles are arranged in regular longitudinal rows. Their length is uniform throughout, except for a few longer cilia at the extreme posterior end of the body, forming a *caudal tuft*, hence the species name *caudatum*.

Electron microscopy has shown that a cilium has the same fundamental structure as has been seen in case of a flagellum. It consists of a fluid matrix, surrounded by an outer membranous sheath, which is continuous with the outer cell membrane of body. Within matrix are 9 peripheral longitudinal fibers, which run along the whole length of cilium body. Each fiber is formed of two sub-fibers, one of which carries a double row of short arms or projections, all running in the same direction (clock-wise). In the centre of matrix are two single fibres, which are enclosed within an inner membranous sheath. In between the central and peripheral fibres are nine additional accessory fibres.

Internal Structure

Paramecium: structure - internal (YOUTUBE)

1.Cytoplasm. Within pellicle, the cytoplasm, al body is clearly differentiated into two regions.

(a) Ectoplasm. The narrow, peripheral, clear and dense zone is called the ectoplasm of cortex. It includes the structure of the intraciliary system and the trichocytes.

(b) Endoplasm. The large, central, granular and semi-fluid zone is the endoplasm or medulla It includes the usual cell components like mitochondria, Golgi bodies, ribosomes, crystals reserve food granules, etc. In P. bursaria, the endoplasm is filled with symbiotic Zoochlorella, a unicellular chlorophyll-bearing alga. Prominent endoplasmic inclusions are nuclei, contractile vacuoles and food vacuoles.

2. Intraciliary system. Immediately near the pellicular alveoli is located the intraciliary System constituted by the basal bodies and kinetodesmata.

(a) Basal bodies. The base of each cilium is produced into a tube-like structure, called base body or kinetosome. It is formed by the thickened basal ends of peripheral fibres d cilium. The central fibres do not enter into the wall of basal body consists of 9 triplets of sub-fibres. The basal bodies are self-duplicating units and progenitors of new cilia. Each basal body is either a centriole or its derivative.

b) Kinetodesmata. Associated closely with basal bodies of cilia and lying in the ectoplasm is a system of specialized striated fibrils, called *kinetodesmal fibrils*. A single fibril kinetodesmosome arises from the kinetosome. or basal body of each cilium and runs anteriorly somewhat tapering along the course. It joins its counterparts from the posterior kinetosomes, forming a bundle of overlapping longitudinal fibrils, called *kinetodesma* (pleural, *kinetodesmata*). The number of fibrils in each kinetodesma remains constant (5), because the individual fibrils do not run anteriorly farther than 5 basal bodies. It has been suggested that fibrils coordinate ciliary beat and movement, but the evidence is very conflicting.

The kinetosomes of a longitudinal row plus their Kinetodesmata constitute a structural unit, called the kiner. A kinety system is apparently characteristic of all ciliates. It is said that the pattern of infraciliature plays an important role in the morphogenesis of Protozoa. For example, in Paramecium, one set of kinety is solely responsible for the development of mouth structure. A new mouth fails to develop if this kinety is removed experimentally.

3. Trichocysts. Trichocysts are peculiar rod-like or oval organelles present throughout the ectoplasm alternating with basal bodies and oriented at right angles. to the body surface. These were first seen in Paramecium by Elis. These are very small in size, measuring about 4 M in length. Each trichocyte consists of an elongated shaft and a terminal pointed tip, called the spike or barb, covered by a cap. The matrix of shaft consists of a dense mass of a fibrous protein, called trichinin. Its fibres remain condensed forming a cross-striated lattice work.

Function of trichocysts is not well known. It is believed that these discharge and anchor the animal to a firm substratum when it feeds upon bacteria. Others believe that these are organelles of defense.

Discharge of trichocysts is triggered by mechanical, chemical or electrical stimulation. It occurs in a span of a few milliseconds. When fully discharged the shaft becomes a long cross-striated rod and measures about 40 g in length. It is believed that the discharge process consists of an unfolding of the lattice of trichinin fibres.

4. Nucleus. Paramecium is heterokaryotic as it possesses two types of nuclei. In P. caudatum, there is a large macronucleus and a small micronucleus. Besides the macronucleus, two micronuclei are present in P. aurelia and many in P. multi micronucleatum.

(a) Macronucleus. The macronucleus is roughly kidney-shaped and with inconspicuous nuclear membrane. It is polyploid and possesses many nucleoli and much more chromatin material (DNA). Macronucleus is the somatic or vegetative nucleus and controls the day-to-day metabolic activities of the cell. it is derived from micronucleus during reproduction processes.

(b) Micronucleus. The micronucleus is lodged in a depression on the surface of the macronucleus. It is usually spherical, with a nuclear membrane and with diploid number of chromosomes. It contains a definite nucleolus in P. aurelia, while in P. caudatum the nucleolus is absent. It controls the reproductive activities of the organism.

5. Contractile apparatus. In Paramecium, unlike amoeba and Euglena, there are two contractile vacuoles, occupying somewhat fixed positions in endoplasm. One vacuole lies near each end of body, close to the dorsal surface. Each of them is surrounded by a circlet of 6 to 10 long, narrow, spindle-shaped radial canals (afferent pulsating canals) extending far into cytoplasm. Each contractile vacuole opens to outside through a permanent pore in pellicle of dorsal side of body. The two contractile vacuoles do not lose their identity when water is expelled.

Electron microscopy has revealed that each contractile apparatus includes some of the tubules of the endoplasmic reticulum, nephridial tubules, feeder canals, accessory vacuoles (radial canals) and the main contractile vacuole. The accessory vacuoles or radial canals are, in fact, the ampullae of feeder canals.

6. Food vacuoles. Numerous non-contractile food vacuoles, recently termed gastrioles by Vokovsky, can be seen moving with the streaming endoplasm (cyclosis). They differ in shape and size according to the nature of ingested food particles, but mostly they are rounded in form.

7. Oral apparatus. In Paramecium, oral groove leads ventrally and posteriorly as a tubular structure, called vestibule. It leads directly into a wide tubular passage, the buccal cavity. In its turn it opens into a narrow gullet or cytopharynx through a narrow aperture, the cytostome. The cytopharynx, at its proximal end, forms a food vacuole.

Buccal cavity, at right side, is bordered by a row of cilia forming the endoral membrane. At left side are. three groups of four rows of cilia, extending from the rim of the opening to the posterior end of buccal cavity. These are ventral peniculus, dorsal peniculus and quadrulus. The ciliary rows constitute the membranelles. For endoral membrane a ribbed pellicle extends up to cytostome. Nemadesmal fibres run dorsal " the ribbed pellicle and extend as post-oral fib around cytopharynx. Rows of normal somatic cilia line the wall of vestibule.

8. Cytopyge. Near posterior end of body little behind cytostome and al little to the right side, a small portion of ectoplasm and pellicle is somewhat weak. Here, at the time of egestion, a minute aperture called cell anus, cytopyge or cytoproct, is visible. It is, however, difficult to say whether it is a permanent opening with tightly-closed lips or a temporary opening formed at the time of egestion.

Locomotion

Paramecium: locomotion (YOUTUBE)

Paramecium has a streamlined body which enables it to swim about in water with a minimum amount of friction. The rapid swimming is facilitated by the beating of fine and hair-like cellular organelles, called cilia, that cover the animal's entire cell-body. Paramecium moves with a speed of 1500м or more per second.

1. Ciliary beats.
   During movement, a cilium oscillates like a pendulum. Each oscillation comprises a fast effective stroke and a slow recovery stroke. During the effective stroke or the strong backward lash, the cilium becomes slightly curved and rigid and strikes the water like an oar, so that body is propelled forward in opposite direction of stroke. The recovery stroke

which follows immediately brings the cilium again into position for the next effective stroke.

All the cilia of body do not move simultaneously and independently but progressively in a characteristic wave-like manner, called meta-chronal rhythm. The cilia in a longitudinal row beat in a characteristic wave beginning at the anterior end and progressing backwards. Consequently, a cilium in a longitudinal row always moves in advance of the one behind it. All the cilia of a transverse row beat simultaneously or synchronously. During forward movement of Paramecium, the metachronal waves pass from the posterior end forwards.

2. Mode of swimming.

   The animal does not follow a straight tract but rotates spirally like a rifle bullet along a left-handed helix. The reason for this is twofold. Firstly, the body cilia do not beat directly backwards but somewhat obliquely towards right, so that the animal rotates over to the left on its long axis. Secondly, the cilia of oral groove strike obliquely and more vigorously so as to turn the anterior end continually away from the oral side and move in circles. The combined effect causes the movement of animal along a fairly straight path, rotating about its axis in an anticlockwise direction.

In backward movement a Paramecium follows a straight course. In this case the metachronal wave passes from anterior end backwards. This is due to the fact that effective stroke is carried out anteriorly.

Mechanism of ciliary movement in Paramecium is little studied. It is now known that cilia are moved in a coordinating system. They move by the contraction of peripheral fibres located within them. The energy needed for fibrillar contraction is supplied by ATP.

NUTRITION

Paramecium: nutrition (YOUTUBE)

1. Food.

   Paramecium feeds in the holozoic manner, like Amoeba. The food consists chiefly of bacteria which float in water in which it lives.

It has been estimated that 2 to 5.5 million individuals of Bacillus coli are devoured in 24 hours by a single Paramecium. In a sense, paramecia are also beneficial to bacteria, lest the might reproduce too rapidly as to endanger their own existence by overcrowding. It also feeds upon small Protozoa, unicellular plants (algae, diatoms, yeasts, etc.) and small bits of animals and vegetables. It will reject most of the non-digestible material and devour certain kinds of food. One species, P. bursaria, is interesting, being green in color due to the presence of numerous unicellular algae, the symbiotic Zoochlorella in its endoplasm. It can thus live holophytically for long periods on food substances manufactured by Zoochlorella. During scarcity of food, it can digest even its own Zoochlorella and can live apparently indefinitely without them.

2. Feeding mechanism.

Paramecium swims to places where it can get its food. Its food catching apparatus is much more specialized than that of Amoeba and Euglena.

Food is ingested by a definite cell mouth or cytostome lying at the bottom of buccal cavity.

The constant lashing movements of cilia of oral groove drive a current of water with food particles towards the vestibule. Ciliary tracts of vestibule direct the food particle into buccal cavity. 'Paramecium is a selective feeder.

According to Mast (1947), many kinds of particles may be carried with water current into vestibule, but only selected ones are passed on inside the buccal cavity. Rest of particles are rejected, that is, discharged to outside. Passage along which ciliary action drives selected food particles, is termed the selection path, whereas passage along which unwanted food particles are driven outside vestibule, is the rejection path.

Beating of cilia of membranelles of buccal cavity drives the selected food particles through cytostome into cell gullet or cytopharynx. The food now gradually collects at the bottom of cytopharynx into a membranous vesicle which is later nipped off as a food vacuole. Another food vacuole may be formed within 1 to 5 minutes depending upon the supply of food and the rate of feeding.

3. Digestion.

Each food vacuole consists of food particles surrounded by a thin film of water.

Rapid and irregular movement of endoplasm does not occur in Paramecium, but the food vacuole is circulated around the body along more or less definite path by a slow streaming movement of endoplasm, known as cyclosis. Several vacuoles may be seen thus circulating it a definite direction in the endoplasm of 1 well-fed Paramecium. The vacuoles are carried. first posteriorly, then forward and aborally and again posteriorly and orally up to cytopyge. Digestion and assimilation of food take place during this journey. Digestive enzymes (proteases, carbohydrates, lipases) are secreted by the lysosomes into the food vacuoles. As in Amoeba, the contents of a vacuole first become increasingly acidic, but later gradually become alkaline. This can be demonstrated with the help of Congo Red and other indicator dyes. The alkaline phase results from the secretion of enzymes within an alkaline medium into the vacuole. Products of digestion (glycogen and fat globules) are diffused into the surrounding cytoplasm and either stored or used for vital activity and growth.

4. Egestion.

The vacuole gradually becomes smaller as digestion and absorption proceed.

Finally, the undigested residual matter is eliminated from body, through a definite anal spot or cytopyge on ventral surface, posterior to cytostome. The cytopyge is of the nature of a potential cell anus as the undigested matter is always discharged at this spot.

Respiration and Excretion:

Respiration takes place, as in Amoeba and other freshwater Protozoa, by diffusion through the semi-permeable pellicle. Oxygen dissolved in water is diffused in and used for oxidation of

protoplasmic molecules. Catabolic waste products such as CO2 and nitrogenous matter (NHs) simply diffuse out into external water because their concentration is always higher in body.
Crystals present in cytoplasm are in fact excretory products, which get dissolved and eliminated with the fluid of contractile vacuoles.

Osmoregulation

[Paramecium: osmoregulation (YOUTUBE)]

The function of the contractile vacuoles in Paramecium is osmoregulation. An excess of water accumulates in body because of continuous endosmosis, the concentration of body cytoplasm being higher than that of external medium. Small quantities of water are also taken in along the ingested food. This excess of water is got rid of by means of contractile vacuoles which contract (systole) and expand (diastole) at regular - intervals, assisted by the contractility of myofibrils.
Water from cytoplasm is secreted into some of the tubules of endoplasmic reticulum from where it flows down the nephridial tubules into feeder canals to accumulate in latter's ampullae (radial canals). The ampullae converge and discharge into contractile vacuole. When vacuole has grown to its maximum size, it contracts and discharges to the exterior, through a pore in pellicle on dorsal side. Posterior contractile vacuole because of the large amount of water being delivered into posterior region by cytopharynx.

Behavior

[Paramecium: behavior (YOUTUBE)]

The way in which an organism establishes an active relationship to its environment is called behaviour. It is largely determined by the environmental influences or stimuli to which the organism is subjected. The responses of light intensity, temperature, concentration of 02, CO2 and different chemicals in water are interesting. These produce definite behavioral patterns or reactive behaviour. The response is positive if the animal moves towards a stimulus, and negative when it moves away.
[1] Avoiding reaction
It is perhaps the most important mode of behaviour exhibited by Paramecium. If a fast swimming individual strikes a solid object, it moves back for a short distance, turns on its side and swims forward again but at an angle to its original path. If it again collides with an obstacic, shows the same negative reaction which is repeated until the animal passes the obstacle or becomes exhausted.
[2] Trial and error reaction
Paramecium can also learn by trial-and-error reaction, involving a series of experiments on the part of animal. It constantly tests water just ahead by drawing it in its oral groove in the form of a cone. If water is loo hot or too cold or if it contains an irritating chemical substance, the animal shows an avoiding reaction. it immediately backs up and pivots upon its posterior end, while the anterior end swings in a circle. Again, it swings forward but in a different direction. If this avoiding

reaction once more brings it into the region of the stimulus, it is repeated. These reactions help the animal to avoid undesirable environment without actually getting into it. Moreover, these bring the animal sooner or later, into the most favorable part of environment.

The responses of Paramecium to different stimuli may be summarized as under:

1. Temperature.

   Response to temperature is thermotaxis. Optimum temperature for Paramecium lies between 24°C and 28°C. An avoiding reaction is given to the temperatures higher or lower than this, until the animals escape or get killed.

2. Light.

   Response to light is phototaxis.

   Paramecia do not respond to ordinary changes of light, but a negative response is shown to strong light, darkness and ultra-violet rays.

3. Touch.

   Response to contact or thigmotaxis is variable. If the more sensitive anterior end is strongly touched with a solid object, the avoiding reaction is given. But a slow-moving Paramecium frequently comes to rest in contact with an object, such as an alga or a plant stem, which can provide rich supplies of food.

4. Chemicals.

   Chemotaxis or response to chemicals is negative in most of the cases. The animals show a definite avoiding reaction and do not enter a drop of weak salt solution. However, a positive reaction occurs with a drop of weak acid solution. The animals also find and select their food in this manner.

5. Water current.

   Paramecia show a positive rheotaxis, orienting themselves with their anterior ends upstream and swimming against the current.

6. Electric current.

   A positive galvanotaxis is shown to weak electric current, the animals moving lowards the negative pole (cathode). A strong current, however, causes them to move backward towards the anode, finally disintegrate and die.

7. Gravity.

   Paramecia generally show a negative geotaxis or response to gravity as seen in a culture contained in a test tube, where they gather close to the surface film with their anterior ends pointed upwards. If paramecia are introduced in an inverted water-filled U-tube stoppered at both ends, they immediately move upward into the horizontal part of the tube.

   When, in moving across the tube, they find their path going downward, they reverse their direction of movement.

Reproduction

[Paramecium: reproduction (YOUTUBE)]

Paramecium reproduces asexually by transverse binary fission and also undergoes several kinds of nuclear reorganizations, such as conjugation, endomixis. autogamy, etc. Under certain conditions of food and temperature, it undergoes encystment.

[I] Transverse binary fission

[Paramecium: binary fission (YOUTUBE)]

During favorable conditions, Paramecium commonly reproduces by transverse or horizontal binary fission, which is at right angles to the longitudinal axis of body. Paramecium stops feeding and its oral groove and buccal structures begin to disappear. While this is happening, the micronucleus starts dividing by the complicated process of mitosis, the nuclear membrane remaining intact. Micronucleus first increases slightly in size and then chromosomes, numbering from 36 to 150, depending upon the race, begin to appear. Each chromosome splits longitudinally to form two chromatids (prophase stage). Paired chromatids now get arranged on the nuclear spindle at its equatorial plane (metaphase stage).

This is followed by separation apart of chromatids and elongation of micronucleus (anaphase stage). By the last stage (telophase stage), micronucleus becomes very much elongated and its two ends become organized into two daughter micronuclei. The daughter micronuclei then separate. Simultaneously, the macronucleus divides a mitotically by simply becoming elongated and constricted in the middle. Two oral grooves now begin to form, one in the anterior half and the other in the posterior half. Two original contractile vacuoles remain, one in each half of the dividing parent individual. Two new contractile vacuoles are later formed. Two new buccal structures also appear. In the meantime, a constriction furrow appears near the middle of body. It deepens and ultimately the cytoplasm is completely divided, resulting into two daughter paramecia. Of the two daughter paramecia, the anterior one is called proter and the posterior, opisthe. These grow to full size and divide again by fission. P. caudatum divides 2-3 times in a day by binary fission. The process is completed in about 30 minutes, though separation of daughter paramecia lakes about one hour or more. The term clone is used to refer to all the individuals that are produced asexually from one parent paramecium. All the members of a clone are genetically alike.

[II] Conjugation

[Paramecium: conjugation (YOUTUBE)]

Paramecium undergoes a sexual phenomenon, which is called conjugation. It is frequently referred to as sexual reproduction, but it is simply a temporary union of two individuals of one and the same species for the purpose of exchanging a part of their micronuclear material.
This remarkable process in Paramecium occurs frequently between binary fissions and is necessary for the continued vitality of the species.

1. Process of conjugation.
   The details of this process differ slightly in different species of Paramecium. The following account refers to *P. caudatum.*

In conjugation, two individuals of preconjugants, from two different mating types, come in contact ventrally and unite by their oral grooves. They stop feeding and their buccal structures disappear. The pellicle and ectoplasm degenerate at the point of contact and 1 protoplasmic bridge is formed between the two individuals, which are now called the conjugants While so united, like the 'Siamese twins, the conjugating pair continues to swim actively and! sequence of complicated nuclear changes takes place in each animal.
The vegetative macronucleus simply breaks of into fragments, which are later absorbed by cytoplasm. The diploid micronucleus of. cad conjugant first grows in size and then divides by meiosis. Thus, 4 haploid daughter micronuclei re produced of which 3 degenerate or become pycnotic and disappear in each conjugant, while he remaining one divides by mitosis forming 2 unequal pronuclei or gamete nuclei. The smaller one is the active migratory gamete nucleus and he bigger one is the passive stationary gamete nucleus. The migratory nucleus of one conjugant hen passes through the protoplasmic bridge to the other individual and fuses with its tationary nucleus, forming a single diploid zygote nucleus or synkaryon. The complete fusion of two nuclei from two different individuals forming a zygote nucleus is termed amphimixis. The two pairing paramecia, after a union of 12 to 48 hours, separate and are now allowed exconjugants. in each exconjugant, the zygote nucleus divides by mitosis. times a rapid succession producing 8 nuclei, of which 4 enlarge to become macronuclei and either 4 become micronuclei. Three micronuclei disintegrate and disappear, while the remaining micronucleus divides, with binary fission of exconjugant. Thus, from each exconjugant two daughter paramecia are obtained, each containing 2 macronuclei and one micronucleus.
The micronucleus again divides with the division of each daughter paramecium, forming two individuals each containing one macronucleus and one micronucleus. Thus, each conjugant produces four daughter individuals at the end of conjugation.

2. Factors and conditions of conjugation.

Conjugation is very complex physiologically. The factors and conditions governing conjugation are several and these may also vary with the species.
(1) Conjugation does not occur under favorable living conditions. Starvation or shortage of s food and a particular bacterial diet or certain chemicals are said to induce conjugation in some species.

(2) A certain range of light and temperature, differing with spices, is said to be essential for conjugation to occur.
(3) In P. caudatum, conjugation usually starts early in morning and is continued till afternoon.
(4) The conjugating individuals are usually smaller in size (2104 long) than the individuals (300-350 g long). normal
(5) A definite state of nutrition is indispensable since starved or overfed individuals generally will not conjugate:
(6) Maupas maintains that individuals must have passed through a desirable number of asexual generations (period of immaturity) before they become sexually mature and conjugate.
(7) The pairing conjugants are isogamous and there is no morphological sexual dimorphism into male and female conjugants.
(8) Conjugation never takes place among the members of a "pure line", that is among the descendants of a single individual. It occurs only between individuals belonging to two different mating types. Thus, a sort of physiologically sexual differentiation exists in Paramecium.
(9) Agglutination favors conjugation.
It is the interaction of mating type substances (proteins) which are localized in cilia.

3. Significance of conjugation.
The significance of conjugation has been much discussed but it still remains uncertain. The following functions or effects are attributed to this process:
(a) Rejuvenation. If binary fission continues repeatedly for several generations, the Paramecium loses its vigour and enters upon a period of depressed physiological efficiency and senescence. The individual ceases to multiply, reduces in size, degenerates in organization and eventually dies off. To avoid this senile decay of race, conjugation is resorted to and the process seems to rejuvenate and revive the lost vigour for asexual reproduction.
However, Woodruff and Jennings do not support the view that conjugation helps in rejuvenescence. Woodruff succeeded in maintaining a culture of paramecia for nearly 36 years, resulting in hundreds of thousands of generations without resort to conjugation.
(b) Nuclear reorganization. During conjugation the nuclear apparatus is reorganized and a readjustment occurs between it and the cytoplasm. Probably the macronucleus loses its potentialities in performing its manifold metabolic activities. Its replacement by a new macronucleus brings renewed vigour and vital, to accelerate the metabolic activities.
(c) Hereditary variation. During asexual reproduction by fission, the hereditary material of the parent passes unchanged on to the progeny, so that all the descendants of one Paramecium have the same inheritance. Th periodic occurrence of conjugation, however, ensures inherited variation. It brings about be blending of two lines of ancestry just as binary reproduction does.
4. Genetic consequences of conjugation, I conjugation takes place between two paramecia one homozygous for a dominant gene (AA) and the other homozygous for its recessive gene (aa), the first generation would be heterozygous (Aa). If the two conjugants are already heterozygous (Aa),

then the resulting progeny would be either homozygous or heterozygous depending upon which gene gets eliminated the stage of disintegration of three micronuclei in each conjugation.

[III] Autogamy

W.F. Diller (1936) described a process of nuclear reorganization in P. aurelia, resembling conjugation, but taking place within a single individual.
He called it autogamy self-conjugation.

1. Process of autogamy.
   During autogamy in P. aurelia, the 2 diploid micronuclei divide by meiosis to form eight haploid daughter nuclei Seven of them disintegrate, while the remaining haploid micronucleus undergoes a mitosis division forming 2 gamete nuclei. Meanwhile, the macronucleus grows into an irregular skein-like mass, which breaks into pieces later to be absorbed in the cytoplasm. The two game nuclei enter a protoplasmic cone temporarily formed near cell mouth and then fuse together to form a completely homozygous diploid zygote nucleus or synkaryon.

This divides twice 10 yield 4 nuclei, 2 of which become macronuclei and 2 micronuclei. The cell body and the micronuclei then divide to form two daughter individuals, each with a new macronucleus and 2 micronuclei. Autogamy rejuvenates Paramecium.

2. Genetic consequences of autogamy.

If autogamy takes place in a Paramecium heterozygous for a dominant gene (Aa), the resulting progeny will depend upon the survival of the gene A or a. If the gene A survives, it will lead to AA individuals or vice versa. Thus, autogamy always results in homozygosity.

[IV] Cytogamy

In 1940, R. Wichterman reported, in P. caudatum, a sexual process without nuclear exchange, termed Cytogamy. The process resembles conjugation in that two small paramecia (200 long) temporarily fuse by their oral surfaces. The early nuclear divisions are also similar to those of conjugation; but there is no nuclear exchange between the individuals (cytogamonts). But, two haploid gamete nuclei in each individual are said to fuse to form a synkaryon, as in autogamy. The process is completed in about 13 hours.

[V] Endomixis

Endomixis (Gr., endon, within + mixis, mingling) is an interesting phenomenon involving a total Internal nuclear reorganization within a single individual in a culture of a pedigreed race of Paramecium, taking place in the absence of conjugation. Woodruff and Erdmann, in 1914, first of all reported endomixis in the bimicronucleate species: P. aurelia, occurring periodically at regular intervals of about 30 days.

The whole process may be summarized as follows:

The vegetative macronucleus degenerates and disappears, while the micronuclei divide twice by mitosis forming 8 daughter nuclei of which 6 degenerate. At this stage Paramecium also divides, each daughter receiving on micronucleus. This micronucleus divides twice forming 4 nuclei, 2 of which become macronuclei and 2 micronuclei, in each individual.

The micronuclei again divide with the binary fission of Paramecium into two daughters, each getting one macronucleus and 2 micronuclei.

Thus, four daughters are produced from a single parent bringing about an intracellular nuclear reorganization and readjustment between the cytoplasm and the nuclear apparatus in each individual.

Question

» Long Answer Type Questions

1. Describe the detailed structure of the pellicle and the infraciliary system of Paramecium
2. Describe the modes of locomotion and nutrition in Paramecium.
3. Describe the feeding mechanism and the process of digestion in Paramecium.
4. Compare the modes of locomotion and nutrition of Amoeba, Euglena and Paramecium.

S. How is osmoregulation effected in Paramecium?

6. Give an account of conjugation in Paramecium and discuss its significance.
7. Describe the processes of autogamy and endomixis in Paramecium.
8. Write short notes on :(I) Amphimixis, (ii) Autogamy, (III) Binary fission in Paramecium, (IV) Buccal ciliature of Paramecium,

(V) Cyclosis, (vi) Endomixis, (vii) Kappa particles, (viii) Synkaryon, (1x) L richocysts.

» Short Answer Type Questions

1. How do the Paramecium feed?
2. Mention the organ of offence and defense in Paramecium.
3. What is endomyxis?
4. What are the two functions of contractile vacuoles of Paramecium?
5. What is meant by undulating membrane? What function does it serve?
6. Give two differences between endomixis and autogamy.
7. Conjugation occurs between mating type of the ... variety.
8. Streaming movements of food vacuoles in Paramecium is known as
9. The descendants of a single individual Paramecium is known as
10. Define conjugation.
11. Write the food procuring mechanism exhibited by Paramecium.
12. What is a trichocyst? What are its functions? Describe the mechanism of its discharge.
13. Distinguish between conjugation and autogamy.
14. What is nuclear dimorphism? Explain the phenomenon with reference to Paramecium.
15. Differentiate between Cytogamy and autogamy, and endomixis and hemixis.
16. Give an account of nuclear reorganization processes in Paramecium.
17. Distinguish between synchronous and metachronous beating of cilia in Paramecium.
18. Distinguish between macro- and micro-nucleus of Paramecium on the basis of their functions.
19. Distinguish between effective stroke and recovery stroke of a flagellum.
20. With reference to plane of division distinguish binary fission in Paramecium and Trypanosoma.
21. Describe cyclosis.

» Multiple Choice Questions

1. Movement of food vacuole in Paramecium along a definite path is known as

   (a) cytokinesis (b) cyclosis
   (c) endomixis (d) metagenesis

2. In Paramecium the division of Macronucleus during Binary fission is:

   (a) mitotic (b) amitotic
   (c) meiotic (d) prenuclear

3. The functions of the Trichocysts are:

   (a) offence and defence (b) narcotising prey
   (c) to attain resting condition (d) all of the above mentioned

4. The main functions of the contractile vacuole is

(a) pumping out excess water (b) excretion
(c) osmoregulation (d) respiration

5. What is a trichocyst?

(a) spindle shaped structure below pellicle
(b) interlacing
(c) fusion of cilia and flagella
(d) modification of the contractile vacuole a structure concerned with photosynthesis

6. Mention a function of the neuro-motor system of Paramecium

(a) co-ordination of ciliary beat
(b) co-ordination of various stimuli
(c) control of digestion
(d) co-ordination of respiratory movement
(e) control of osmoregulation

7. Which of the following helps in anchorage and defence of Paramecium?

(a) nematocyst (b) oocyst
(c) trichocyst (d) statocyst

8. Autogamy and conjugation are sexual processes, because

(a) recombination of genes takes place
(b) the individual is rejuvenated
(c) two individuals are involved
(d) fusion of haploid nuclei occurs

9. The number of nucleus in Paramecium is :

(a) one (b) two
(c) three (d) four

10. Who discovered Paramecium

(a) Hill (b) Ross
(c) Lavine (d) Grassi

11. 'Hay-infusion method' use for the culture:

(a) Amoeba (b) Paramecium
(c) Euglena (d) all

12. "Caudal tuft' present in

(a) Amoeba (b) Paramecium

(c) Euglena (d) Trypanosoma

13. Vegetative function control by:

(a) Micronucleus (b) Macronucleus

(c) both (d) none

14. How many food vacuole present in Paramecium

(a) one (b) two

(c) four (d) numerous

15. Among them which one is filter feeder

(a) Paramecium (b) Amoeba

(c) Trypanosoma (d) Monocystis

16. A protozoa feeds on protozoans:

(a) Paramecium (b) Amoeba

(d) Plasmodium (c) Trypanosoma

17. Protozoa which able to creep on a substratum

(a) Amoeba (b) Paramecium

(c) Euglena (d) none

18. How many paramecia produce after the conjugation

(a) two (b) four

(c) eight (d) sixteen

19. Autogamy occurs only in:

(a) Paramecium cadatum (b) P. aurelia

(c) Amoeba (d) Trypanosoma

20. Cytogamy occurs in:

(a) Paramecium caudatum (b) P. aurelia

(c) Amoeba (d) none

ANSWER

1. (b) 2. (a) 3. (d) 4. (c) 5. (a) 6. (a) 7. (c) 8. (b) 9. (b) 10. (a) 11. (b) 12. (b) 13. (b) 14. (d) 15. (a) 16. (a) 17. (a) 18. (b) 19. (b) 20. (a).