Paramecium reproduces both asexually and sexually. It also undergoes several kinds of nuclear organizations. It can also multiply during nuclear organizations. Various processes of reproduction in Paramecium are listed below

VARIOUS PROCESSES OF REPRODUCTION IN PARAMECIUM

Nuclear Organisation and its Importance

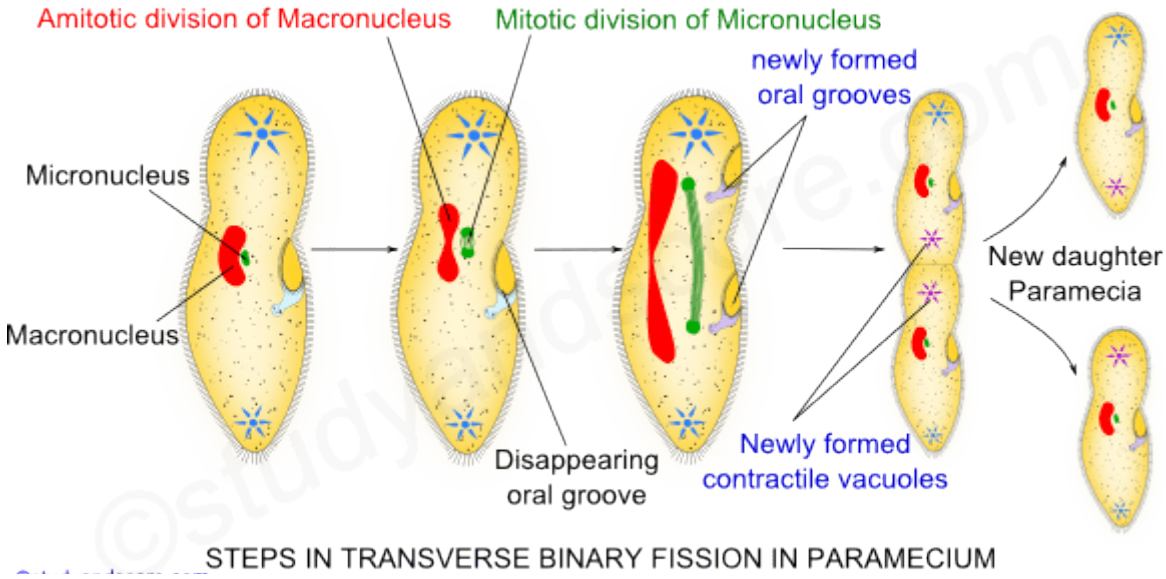
The degeneration of old macronucleus and the formation of the new one by fusion of micronuclei is called as nuclear organization. In binary fission the macronucleus divides by amitosis in which chromosomes are distributed at random to the daughter macronuclei. Due to repeated binary fission, genic balance of macronucleus is disturbed. This imbalance reduces the vigors and vitality of the clone. Rate of binary fission also reduces. For example, it has been shown that some species of paramecium can pass through only about 320-350 continuous asexual binary fissions. If the nuclear organization fails to occur, the asexual clone dies.

Replacement of the imbalanced macronucleus thus is very important. The new macronucleus has rejuvenating effect on the clone. A new macronucleus is produced by the following processes:

1. Conjugation
2. Autogamy
3. Endomixis
4. Cytogamy

Whereas, binary fission is an asexual reproduction process in which nuclear organization does not occur.

Transverse Binary Fission



STEPS IN TRANSVERSE BINARY FISSION IN PARAMECIUM

- Transverse binary fission is the commonest type of asexual reproduction in Paramecium. It is a distinctly unique asexual process in which one fully grown specimen divides into two daughter individuals without leaving a parental corpse.
- *Paramecium* stops feeding before initiating binary fission and then its oral groove disappears.
- The plane of division is through the centre of the cell and in a plane at right angles to the long axis of the body. Division of the cell body as a whole is always preceded by division of the nuclei; indeed it appears that reproduction is initiated by nuclear activity and division.
- Paramecium Caudatum reproduces by transverse binary fission during favourable conditions. In binary fission, the micronucleus divides by mitosis into two daughter micronuclei, which move to opposite ends of the cell. The macronucleus elongates and divides transversely by amitosis.ss
- Another cytopharynx is budded off and two new contractile vacuoles appear, one near anterior end and another near posterior end. In the meantime, a constriction furrow appears near the middle of the body and deepens until the cytoplasm is completely divided.
- The resulting two **"daughter"** paramecia are of equal size, each containing a set of cell organelles. Of the two daughter paramecia produced, the anterior

one is called proter and the posterior one is called opisthe. They grow to full size before another division occurs.

- The process of binary fission requires about two hours to complete and may occur one to four times per day, yielding 2 to 16 individuals. About 600 generations are produced in a year.
- The rate of multiplication depends upon external conditions of food, temperature, age of the culture, and population density; also on the internal factors of heredity and physiology. Naturally, if all the descendants of one individual were to survive and reproduce, the number of paramecia produced would soon equal to the volume of the earth.
- The term clone is used to refer to all the individuals that have been produced from one individual by fission. All the members of a clone are hereditary alike.

SEXUAL REPRODUCTION: CONJUGATION

In *Paramecium,* Conjugation is a form of sexual reproduction. It is a temporary union of two individuals of same species for mutual exchange of genetic materials. Continuous multiplication by binary fission is interrupted by conjugation as it is necessary for the survival and rejuvenation of the race..

Sonneborn (1947), on the basis of mating behaviour of Paramecium Caudatum, has reported that each species of Paramecium exists in a number of varieties or syngens. Further, within each syngen there are a number of mating types usually two.

The mating types remain morphologically identical but they exhibit physiological differences. In P. aurelia, there are 14 syngens and 28 mating types, while in P. caudatum, there are 16 syngens and 32 mating types. Observations have been made that usually paramecia neither conjugate with members of their own mating type nor with the other varieties, but only with the second mating type of their own variety.

The factors inducing conjugation vary from species to species but some of them are given below:

- Conjugation occurs usually under un-favourable living conditions; starvation or shortage of food and particular bacterial diet or certain chemicals are said to induce the process of conjugation in certain species of Paramecium.
- Conjugation occurs after about 300 asexual generations of binary fission, or it alternates with binary fission at long intervals to rejuvenate the dying clone, i.e., it occurs in the individuals which must have passed through desirable number of asexual generations, said to be the period of immaturity, and then they become sexually mature to conjugate.
- Conjugation occurs when there is a change in the physiological condition of paramecia, then it occurs between such individuals which are somewhat smaller in size (210 microns long) and they are at a stage which may be regarded as a period of unhealthy old age; the paramecia of this condition will die if not allowed to conjugate.
- Sudden darkness in light conditions and low temperatures are said to induce the process of conjugation in some species.
- Conjugation does not take place during night or darkness; it starts in early morning and continues till afternoon.
- A proteinaceous substance in the cilia of mating type individuals is said to induce conjugation.

Process of Conjugation:

The process of conjugation differs in different species of Paramecium, but the undernoted account relates to the conjugation process of P. caudatum.

In conjugation two Paramecium caudatum (referred to as pre-conjugants) of the opposite mating types of the same variety come together with their ventral surfaces and unite by their oral grooves; their cilia produce a substance on the surface of the body which causes adhesion of the two conjugating paramecia.

They stop feeding and their oral groove apparatus disappears. The pellicle and ectoplasm, at the point of contact, of both break down, and a protoplasmic bridge is formed between the two animals. Now, these individuals are called conjugants.

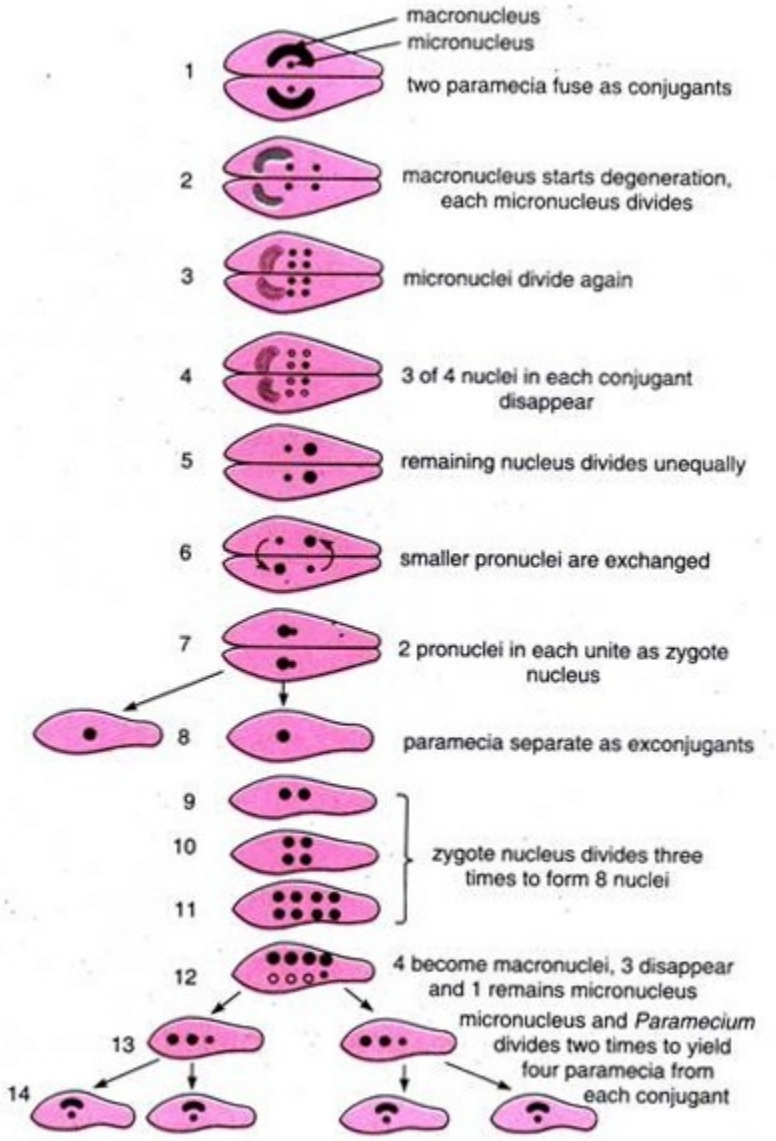


Fig. 20.21. *Paramecium caudatum.* **Stages of conjugation.**

In this condition, the conjugating pair swim actively and simultaneously a series of nuclear changes take place in each conjugant as described below: The macronucleus begins to disintegrate, it becomes loose in texture and forms a complex twisted skein, during the latter half of the conjugation period it will finally disappear being absorbed in the cytoplasm. The micronucleus of each conjugant divides twice, one of them being a reduction division.

Thus, four haploid daughter micronuclei are produced in each conjugant. Three of these four micronuclei degenerate in each, so that only one remains.

The remaining micronucleus of each conjugant divides mitotically into two unequal pronuclei or gametic nuclei forming a larger stationary female pro-nucleus and a smaller, active migratory male pro-nucleus.

The migratory pro-nucleus of one conjugant crosses over the protoplasmic bridge and fuses with the stationary pro-nucleus of other conjugant to form a synkaryon or conjugation nucleus in which the diploid number of chromosomes is restored and there has been an exchange of hereditary material.

The process has been compared with fertilisation in higher animals, but this is not fertilisation because no gametes are involved. The conjugants now (after about 12-48 hours) separate and are called ex-conjugants. The synkaryon of each ex-conjugant divides three times to form eight micronuclei in each ex-conjugant.

Four of the eight micronuclei enlarge and become macronuclei, and three of the other four micronuclei disappear.

The remaining micronucleus divides and at the same time the ex-conjugant divides by binary fission into two cells, each having two macronuclei and one micronucleus. The cells and their micronuclei divide a second time to form four paramecia from each ex-conjugant, so that each has one macronucleus and one micronucleus.

The new macronucleus, as also the micronucleus, have been made of new material. These new nuclei probably contain new and different potential which is reflected in the healthy individuals.

Significance of Conjugation

A clone will die out if nuclear re-organisation does not occur, but the clone can be rejuvenated to regain its former vigour by nuclear rearrangement, this nuclear re-organisation is brought about by conjugation, thus, conjugation is essential for continued binary fission.

The significance of conjugation has been summarised below

1. Conjugation serves as a process of rejuvenation and re-organisation by which the vitality of the race is restored. If conjugation does not occur for long periods, the paramecia weaken and die. (Woodruffs claim of keeping paramecia healthy for 22,000 generations without conjugation is disproved by Sonneborn, because he showed that all of Woodruffs paramecia belonged to the same mating type).

2. There is no distinction of sex in conjugants though only paramecia of two different mating types of the same variety will conjugate.

3. There is no distinction of sex, yet the active migratory pro-nucleus is regarded as male and the stationary pro-nucleus as the female.

4. Conjugation is only a temporary union, there is no fusion of cytoplasm and no zygote is produced, but the nucleus of each ex-conjugant contains hereditary material from two conjugating individuals.

5. Conjugation brings about replacement of the macronucleus with material from the synkaryon, this is an event of fundamental importance. In binary fission the chromosomes of the macronucleus were distributed at random to the daughter cells, continued binary fission had made the clone weak with some structural abnormalities.

Conjugation brings about the formation of the correct number of chromosomes in the macronucleus, so that the race is renewed in vigour. The role of the micronucleus is to restore a balanced chromosome and gene complex.

Aberrant Behaviour in Reproduction in Paramecium Caudatum

Paramecium Caudatum shows certain variations in its nuclear behaviour during fission and conjugation, these deviations are endomixis, autogamy, cytogamy and hemixis. In the first three processes genetic recombination is effected and a new macronucleus is formed from the micronucleus.

(i) Endomixis:

Woodruff and Erdmann (1914) first of all reported a new nuclear re-organisation process, endomixis (Gr., endon = within; mixis = mingling) in Paramecium aurelia, a bimicronucleate species (Fig. 20.22). This process was described as occurring

periodically in which a new macro-nuclear apparatus is produced without synkaryon formation. Endomixis occurs within a single individual.

According to Woodruff and Erdmann, the macronucleus degenerates and the micronuclei divide twice to form eight micronuclei. Six micronuclei degenerate and two remain. With only two micronuclei remaining, the animal divides by fission into two cells, each with one micronucleus.

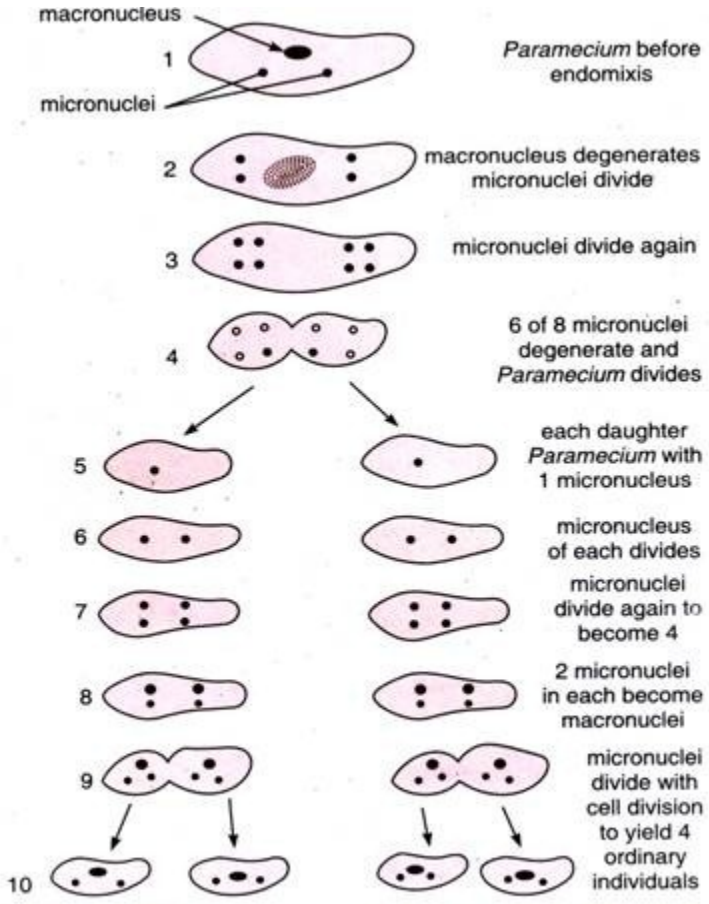


Fig. 20.22. *Paramecium aurelia*. Diagram showing nuclear changes during endomixis.

The micronucleus of each daughter cell divides twice to form four micronuclei. Two micronuclei enlarge to form macronuclei. The animal and its micronuclei divide so that two daughter individuals are formed, each having one macronucleus and two micronuclei.

Endomixis occurs in that variety of P. aurelia which does not conjugate, hence, the effect of endomixis may be the same as that of the conjugation since both

processes bring about replacement of the macronucleus with material from the micronucleus, and both processes rejuvenate the vitality of the race.

But the two processes differ because there is no fusion of pronuclei in endomixis; endomixis may be compared to parthenogenesis.

However, some workers have claimed with good reasons that endomixis is not a valid process and it has been described due to faulty observation. In all probability endomixis does not take place and it may only be a specialised case of autogamy.

Later, Erdmamm and Woodruff (1916) reported endomixis in Paramecium caudatum. Diller, however, does not believe in the validity of this process and feels that Erdmann and Woodruff have simply combined the stages of hemixis and autogamy into one scheme, endomixis.

(ii) Autogamy:

Diller (1934, 1936) and Sonneborn (1950) described a process of self-fertilization or autogamy occurring in single individual in Paramecium aurelia (Fig. 20.23). He reported that in autogamy three micro-nuclear (pregamic) divisions, involving maturation, produce the gametic nuclei (pronuclei).

During autogamy in P. aurelia, the two micronuclei divide twice (once meiotically) to form eight micronuclei, six of which degenerate. Meanwhile the macronucleus grows into skein-like mass which breaks into pieces later to be absorbed in the cytoplasm. Two of the eight micronuclei, as pronuclei, enter a protoplasmic cone bulging near the cell mouth.

The two pronuclei fuse to form synkaryon. The synkaryon divides twice to form four micronuclei. Two micronuclei become macronuclei. The Paramecium and its micronuclei divide to form two daughter individuals, each with one macronucleus and two micronuclei. This process is completed in about two days.

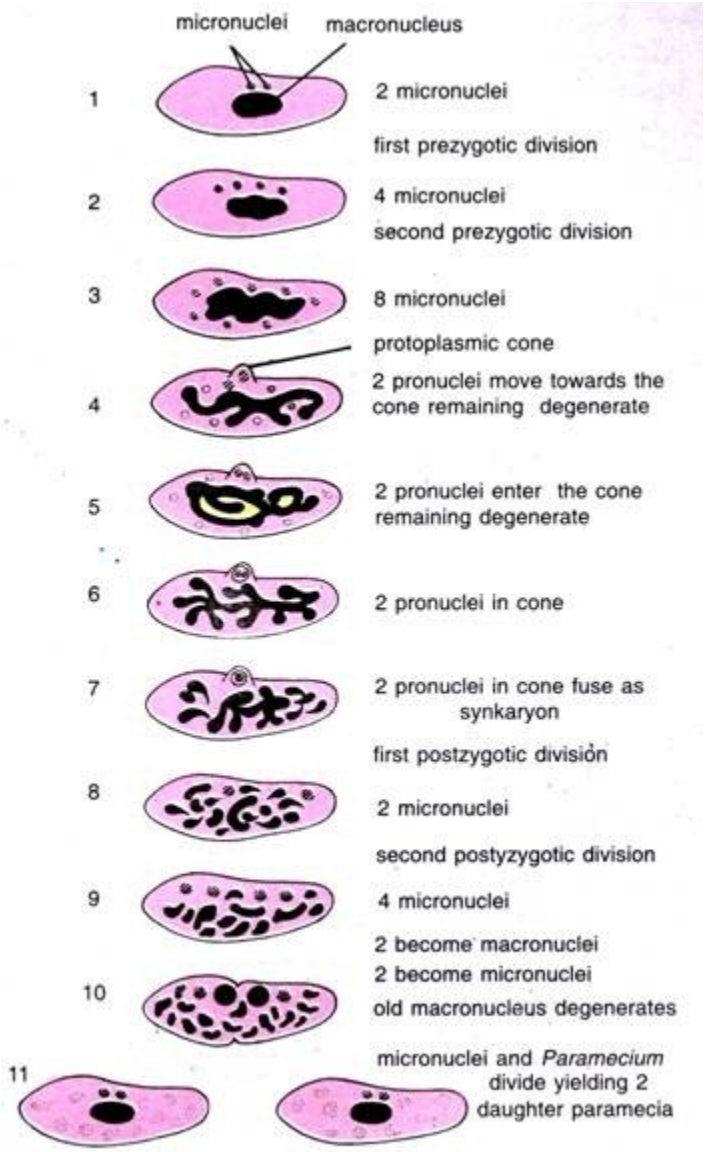


Fig. 20.23. *Paramecium aurelia*. Diagram of the nuclear changes during autogamy.

Autogamy brings about rejuvenation of the race.

It resembles conjugation in as much as the new macronucleus is formed by material from the micronucleus, in the new macronucleus correct number of chromosomes is restored; and also in the fact that fusion of two pronuclei occurs. But autogamy differs from conjugation because only one individual takes part in autogamy and it provides both the pronuclei, it is a kind of self fertilization.

(iii) Hemixis:

Diller (1936) reported the hemixis in Paramecium aurelia (Fig. 20.24). Hemixis is primarily a process of macro-nuclear fragmentation and division without any unusual micro-nuclear activity. Diller classified hemixis into four types, namely A, B, C, and D as shown in Fig. 20.24 in P. aurelia but he also encountered all types in mass cultures of P. caudatum and P. multimicronucleatum.

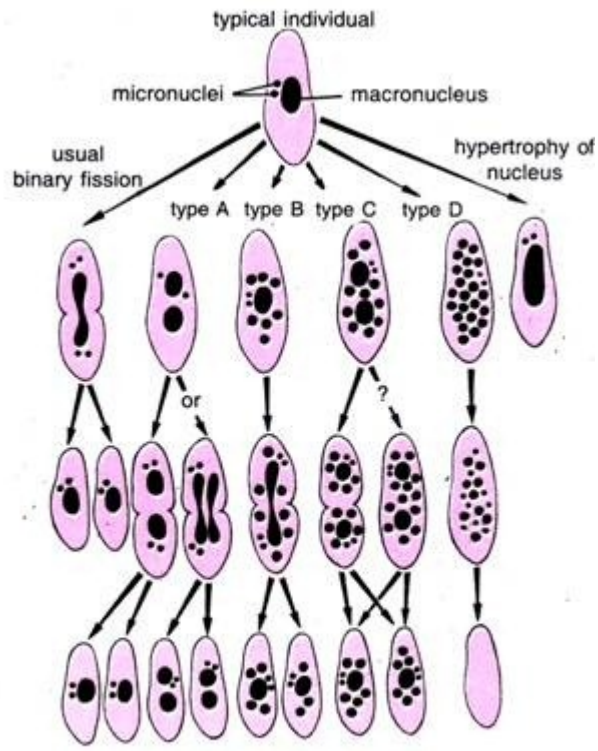


Fig. 20.24. ***Paramecium aurelia.*** **Diagrams of the macronuclear behaviour during hemixis.**

Type A is the simplest form of hemixis characterised by a division of the macronucleus into two or more parts. This division is not synchronized with micro-nuclear division.

Type B is characterised by the extrusion of one to 20 or more chromatin balls from the macronucleus into the cytoplasm.

Type C is characterised by the simultaneous splitting of the macronucleus into two or more major portions and the extrusion of macro-nuclear balls into cytoplasm.

Type D is considered to represent pathologic conditions in which the macronucleus undergoes complete fragmentation into chromatin balls that eventually disappear from the cell. Micronuclei generally disappear before the dissolution of the macronucleus.

(iv) Cytogamy:

Wichterman (1939) has reported another sexual process in Paramecium caudatum, which he termed cytogamy. In cytogamy, there is no nuclear exchange. In this process, two individuals come together by their ventral surfaces, but the pellicle of the two individuals does not break down.

The micronucleus of each individual divides thrice to form eight micronuclei, six of which disintegrate in each individual. The two remaining micronuclei fuse to-form a synkaryon in each cell. The animals now separate.

Cytogamy differs from autogamy in that there are two animals in contact with each other, but it resembles autogamy and conjugation in the fusion of two pronuclei. Cytogamy differs from conjugation in that there is no nuclear exchange between the two animals which come together.