The Cell, Cell Division and Cell Reproduction

The Cell

The cell may be defined as a piece of nucleated cytoplasm surrounded by a cell wall (in plants) or a membrane (in animals). A group of cells is called a tissue. The cell theory was first formulated by Schleiden and Schwann in 1838. According to their theory, the cell is the structural unit of living organisms and that new cells arise from the pre-existing cells.

A cell is composed of living and non-living parts; the various parts of a typical cell are briefly described as follows:

(a) Non-living: Protective membrane or cell wall and vacuole.

(b) Living : Protoplast—structurally differentiated into nucleus or nucleoplasm and cytosome or the cytoplasm.

(a) Non-living Parts

(i) Cell wall: Non-living, a protective structure deposited by the cytoplasm surrounding the living material, permeable or semi-permeable.

(ii) Vacuole: Present mostly in plant cells and less so in animal cells, frequently serves as a store for non-living substances such as, minerals starch, food particles and other by-products of metabolic activity of the protoplasm; such substances are called inclusions. (suspended in the cytoplasm, as a granule.) A body

(b) Living Parts

(i) Nucleus: It is the most conspicuous, and essential part of the cell, globular in structure, centrally located in a young cell, but in older plant cells it usually attains a peripheral position. It has its own organisation as given below:

(1) *Chromatin:* Deeply staining, appear threadlike during

stainable substances, consisting of DNA, RNA and various protein, that form chromosomes during cell division interphase but during cell division appears organised as chromosomes which are the carriers of hereditary information.

(2) *Karyolymph:* Except chromatin, the rest of the nucleus is filled with nuclear sap or karyolymph. It is a stain-resistant material.

(3) *Nucleolus* (Pl. nucleoli): Darkly-staining, round body, one or more found in a nucleus, visible in interphase and early prophase of the cell division, supposed to act as organiser for nuclear material.

(4) *Chromosome:* The chromosomes known as the nuclear bodies, have their own special organisation; they are capable of self-reproduction during the cell division and maintain their morpho-physiological properties during the life cycle of an organism.

The chromosomes, their behaviour, equational distribution at mitosis and reduction in their number during meiosis were adequately understood before the discovery of Mendel's work. Chromosome is a Latin word meaning "the coloured body" which in the natural stage is colourless but can take colour, when stained with some specific dyes (Carmine, basic fuchsin etc.) particularly during the process of cell division. They lie within the nuclei of the living cell except for a short time during cell division when the nuclear wall disappears. The chromosome number remains constant from species to species; the body cell maintains the diploid number (2n) while the sex cells have haploid number (1n) where the number is reduced to one half in the process of gamete formation. The chromosomes also change in shape and form during the various phases of cell division. Such changes are cyclic and at the end of each cell division the original form of the chromosome is restored. Each chromosome can be distinctly recognised due to its definite form and morphology. Salivary gland chromosomes of the fruit fly, by virtue of their large size, are called giant chromosomes.

(ii) Cytoplasm: Bounded by plasma membrane from outside and similarly by membranes of nucleus and vacuoles from inside, chemically complex, storehouse for various enzymes and cannot live long without nucleus. Plasmagenes and cytogenes are believed to be equivalent to the nuclear genes; these are self-duplicating.

(iii) Mitochondria: Very small structures, visible by special techniques, mostly round or rod-like in shape; they lie free in the cyto-plasm but usually aggregate near the nucleus and increase in number by simple division.

(iv) Golgi bodies: Present only in the animal cells and in the cells of certain lower plants, absent in higher plant cells, appear as a continuous network of strands; they are conspicuously present in secretory cells.

(v) Plastids: Three main types are recognized:

(1) Chloroplasts: develop green colouring pigments.

(2) Leucoplasts: colourless in plant parts not exposed to light.

(3) Chromoplasts: develop yellow and orange pigments. They increase in number by simple division.

(vi) Centrosome: Present in many animals and lower plant cells, lie near nuclear membrane, darkly-staining, granule present in the centre, gives out asters during cell division, divide into two during cell division and assume polar positions.

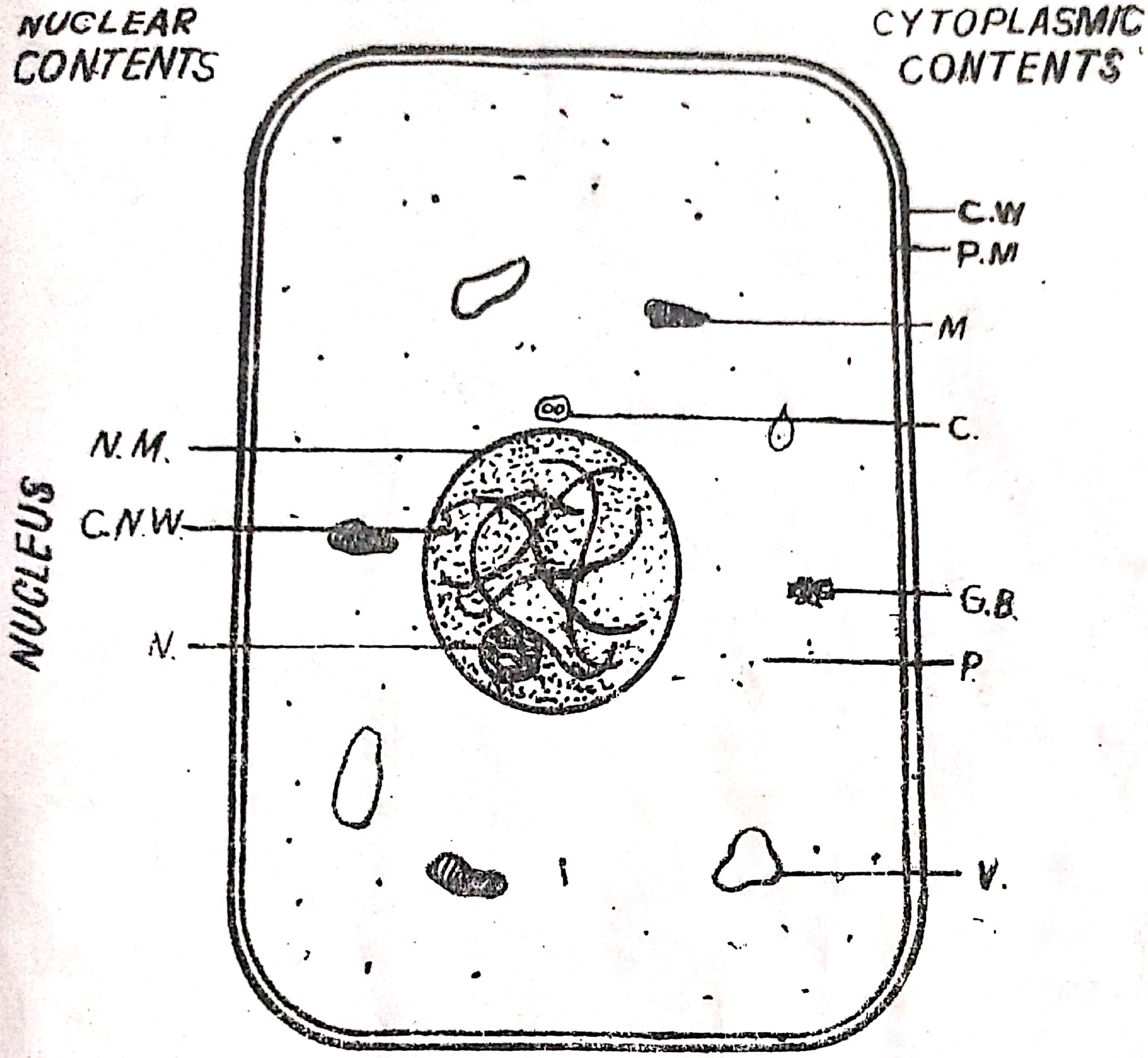
Cell Division

Two types of cell divisions occur in the life cycle of a living organism and they are, (i) Mitosis (ii) Meiosis.

1. *Mitosis:* Throughout the development of an individual from the zygotic stage upto its maturity, the individual grows by *mitosis*, which may be defined simply as an equational cell division. When a cell divides by mitosis into two daughter cells, the chromosomal components equally distribute to the two resulting daughter cells. This equational distribution is achieved through four phases of mitosis, namely, (1) Prophase, (2) Metaphase, (3) Anaphase and (4) Telophase which are briefly described below:

Prophase

The chromosomes shorten in length and get thicker, each chromo-some appears double-stranded as if split longitudinally into two chromatids held by the centromere; the nucleolus evident in the beginning disappears during late prophase.

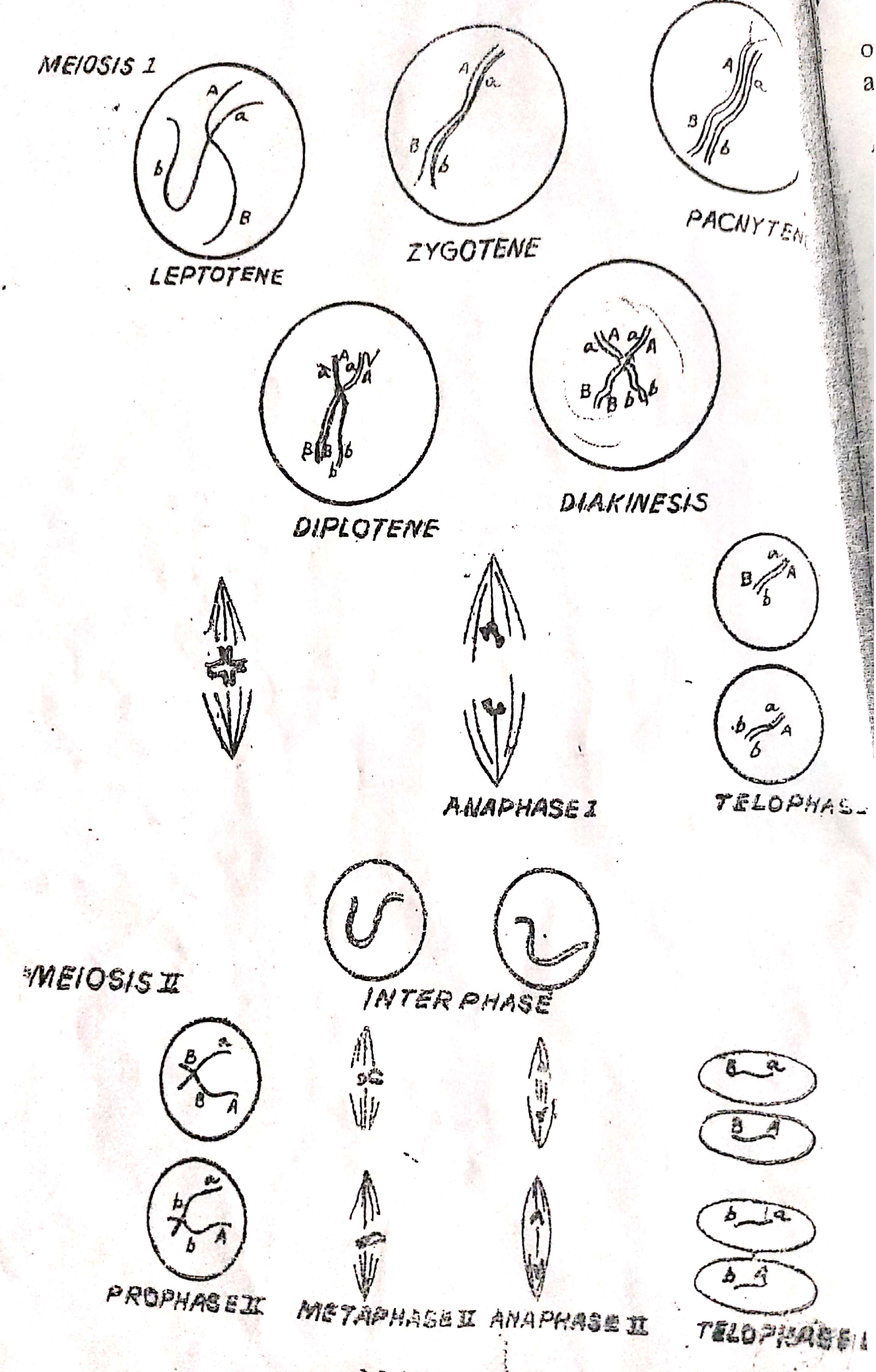


C.W. CELL WALL.
P.M, PLASMA MEMBRANE.
C. CENTRIOLE.
G.B, GOLGI BODY
D. PLASTIDS
V. VACUOLE.
N.M, NUCLEAR MEMBRANE
C.N.W, CHROMATIN NET WORK
M. MITOCHONDRIA
N. NUCLEOLUS.

Fig. 1

A Plant Cell

FIG. 2



Melotic Divisions

Metaphase

The chromosomes shortened to the maximum, orient themselves on the equatorial plate in the centre of the cell; the spindle fibres appear and the centromeres get attached to them.

Anaphase

The centromeres split and move towards the poles, pulling each of the two chromatids to the opposite pole. As a result, each pole receives an identical group of daughter chromosomes; the chromosomes have now divided equationally.

Telophase

Each chromatid attains the status of an independent chromosome, the nuclear wall develops. The chromosomes again elongate to become threadlike and disappear from view to enter interphase. With the completion of the telophase, the mitotic division is complete, producing a new cell which is a precise copy of the original cell.

2. *Meiosis:* Meiosis, on the other hand, occurs in the life cycle of an individual, a plant or an animal, only when it has attained complete differentiation and development of its reproductive organs. Unlike mitosis, meiosis is not equational in nature but reductional. That is, it brings about reduction in the number of chromosomes to half the original number. For instance, if the dividing cell has 20 chromosomes as in maize, the resulting daughter cells at the end of meiosis will have 10 chromosomes each. Meiosis results in the germ cells (gametes) having half the chromosome number characteristic of that individual. The union of male and female gametes, each having the haploid number of chromosomes, restores the characteristic chromosome number, which may be diploid, tetraploid or of a still higher order.

Meiosis consists of two successive division cycles, which may be called Division I and Division II. Division I has a relatively prolonged prophase followed by the same phases as described for mitosis. At the end of Division I, the number of chromosomes in the two resulting daughter nuclei is halved. These two daughter nuclei undergo Division II, which in its mechanism and operation, is like mitosis, and further divides the nuclei into two cells each, and this time the number of chromosomes is not halved, but remains the same as at Division I.

Meiosis in its various phases may be briefly described velow:

A. **Meiosis I (Division I)**

1. Prophase: Sub-divided into five or more phases.

(a) *Leptotene.* Cell size (meiocyte) relatively larger than surrounding somatic cells; chromosomes long thread like and slender, beadlike structures (chromosomeres) on the chromosomes are identified.

(b) *Zygotene.* Homologous chromosomes synapse lengthwise each chromosome divides into two chromatids and the tetrad condition develops.

(c) *Pachytene.* Chromosomes shorten and thicken but are still threadlike; homologues closely attached to one another, already synthesised chromatids start separating longitudinally, relational coiling occurs, nucleolus clearly seen.

(d) *Diplotene.* The four chromatids (tetrad) open out, start repelling each other but remain connected at certain points called chiasmata (singular : chiasma), chromatids exchange corresponding portions by crossing-over, chromosomes further shorten due to tightening of coils.

(e) *Diakinesis.* The chromosomes further shorten to about one tenth of their length in the leptotene stage, deeply stained pairs may assume typical configurations, nucleolus generally disappears.

2. Metaphase: Nuclear membrane disappears and spindle fibres appear, chromosomes orient themselves on to the equatorial plate and centromeres lie along the axis of the spindle.

3. Anaphase: Chiasmata between the paired chromosomes are released and each dyad (the two sister chromatids all original or comprising a crossover) migrates towards any of the two poles; chromatids are

held on together by undivided centromere. Reduction of chromosomal complement is completed.

4. Telophase: Chromosomes arrive at the poles, two new daughter nuclei with haploid number of chromosomes are formed; is the reverse of prophase; reduction is completed quantitatively, but not necessarily qualitatively.

The two newly formed nuclei enter interphase, rest for a while in some cases before second meiotic division starts. The four stages of the second part of meiosis (Meiosis II) are completed in quick succession.

B. Meiosis II (Equational Division)

1. Prophase: The chromosomes regain threadlike structure, which thicken and shorten as the stage advances; chromatids of the dyads are attached to the centromere, each chromatid may be qualitatively different from its mate depending upon whether or not crossing over has occurred.

2. Metaphase: Chromosomes move on to equatorial plate, spindle fibres appear and are attached to the centromeres.

3. Anaphase: Centromere divides, chromatids separate, each becoming an independent chromosome, segregating to the two poles.

4. Telophase: Chromosomes reach the poles; loose their identity, nuclear membrane reappears (reverse of prophase). The end product in plants is a four-celled structure, (quartet) each individual cell results into gametes as explained below:

Reproduction. The sex cells thus formed will become reproductive cells after certain modifications. In animals they are directly transformed into functional gametes, whereas in plants they go through a gametophytic phase which then forms the true gametes.

The cells in which meiosis is initiated are called primary meiocytes, and the cells resulting from the Division I of meiosis are the secondary meiocytes. If a primary meiocyte produces spores (in plants) it is called sporocyte, i.e., primary microsporocyte and primary megasporocyte and the phenomenon is known as sporogenesis. If a primary meiocyte produces sperms or eggs (animals) it is called primary spermatocyte and primary oocyte, respectively, and the phenomenon is termed gametogenesis. These processes of gamete formation are now described below.

1. Gametogenesis in animals

(a) *Spermatogenesis* (Spermiogenesis). Sperm (male gamete) is produced in the male reproductive organs through meiotic division as already explained. A cell of the reproductive tissue, the spermatogonium, enlarges in size and therein meiosis is initiated. The cell is called primary spermatocyte. This undergoes the first meiotic division to produce two secondary spermatocytes with half the chromosome number. A secondary spermatocyte divides again by second meiotic division, and as a result, four spermatids are formed. The spermatids are immotile, change in shape, and develop tails and thus become motile. A functional, active spermatid is called a sperm (male gamete).

(b) *Oogenesis* (*Ovagenesis*). The female gamete in animals is the egg which has a large size than the male gamete (sperm) because it contains cytoplasm which serves as a food nutrient for the developing embryo. The mechanism of cell division is precisely the same as described before except that the size of the cells produced at the first and second meiotic divisions is conspicuously variable. The oogonium prior to the reductional division (meiosis) enlarges in size and is called primary oocyte, which divides (first reduction division) to form one lage-size secondary oocyte and one small-size cell, the first polar body. The difference between the two is in size only (cytoplasm) while the nuclear contents are essentially equal. The secondary oocyte (ovacyte) further divides into two cells of unequal size; the larger one becoming the egg and the smaller the polar body. The first polar body also divides into two polar bodies of equal size. The end product is, therefore, four cells; three are polar bodies which are not sexually functional and the fourth one is the egg cell which functions as the female gamete without any further change.

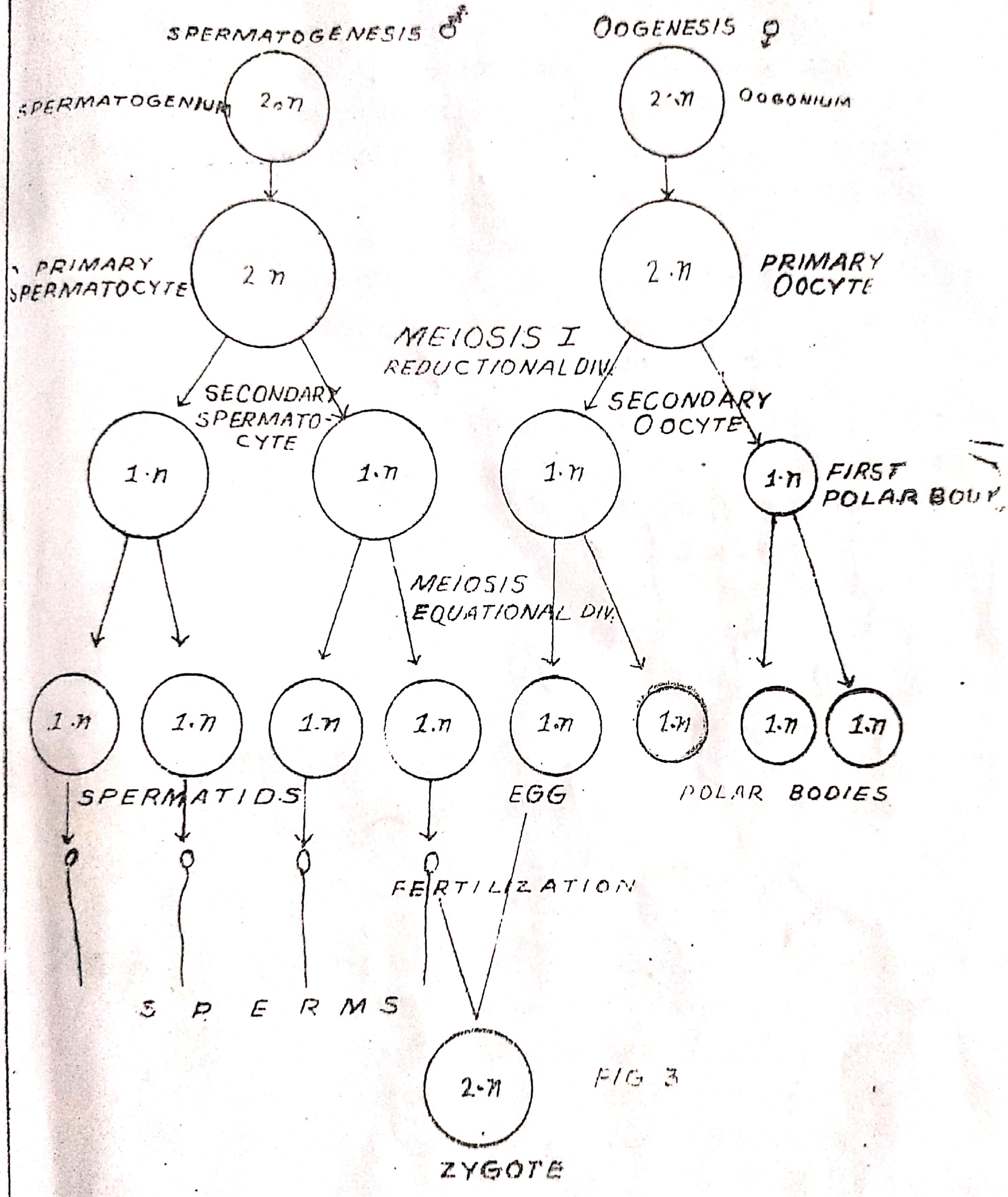
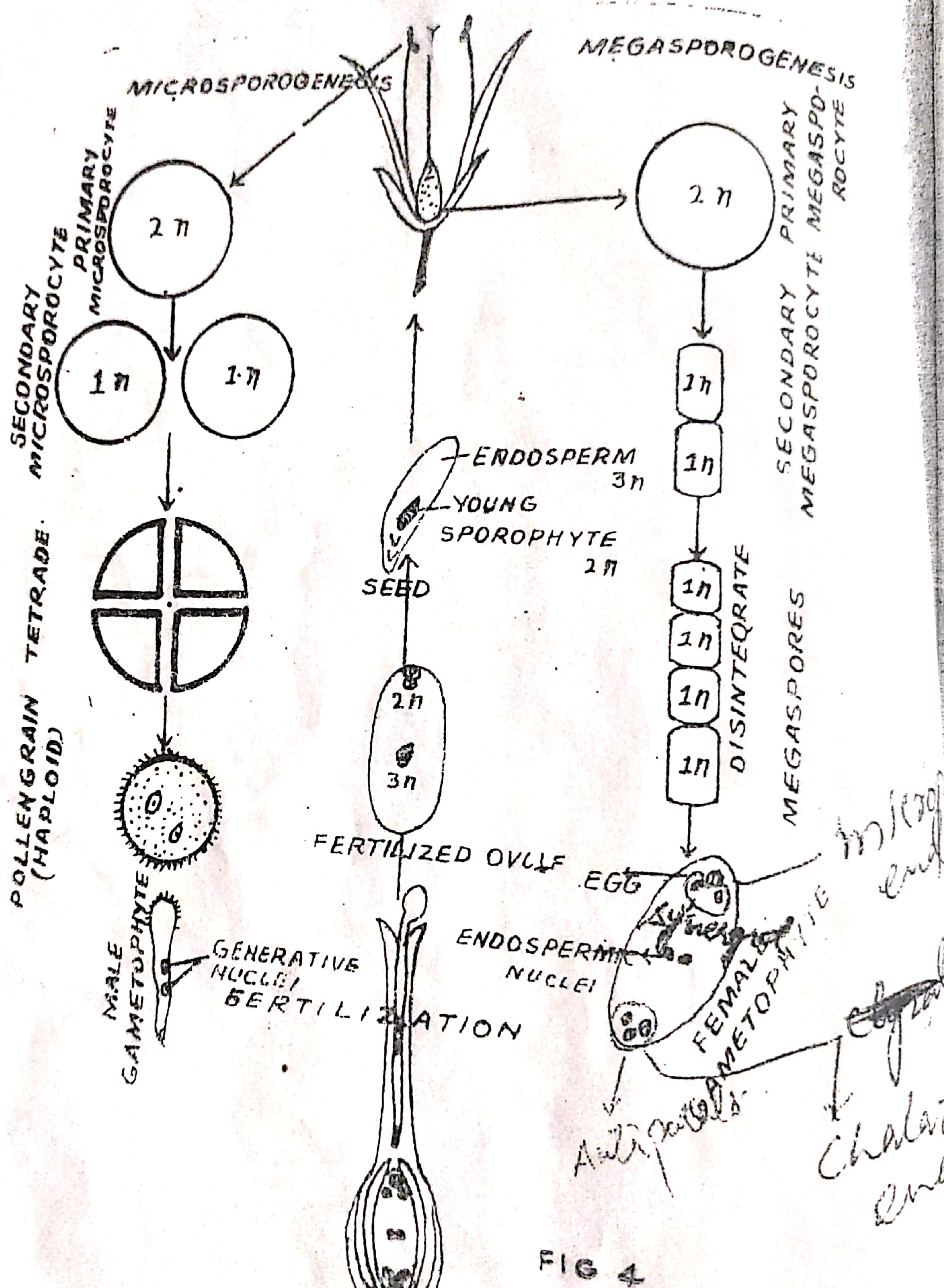


FIG 3

Gametogenesis



Lifecycle of a seed plant

2. Gametogenesis in plants (Sporogenesis)

The process of gamete formation in plants is not as direct as in animals, because in plants an alternation of generation is involved that is, the gametophytic stage follows the sporophytic stage. The sporophyte forms spores through reduction division, which do not function directly as gametes, but first develop a gametophyte which in turn forms the sexual gametes. In higher plants the gametophytic phase is very short-lived. A brief description of gametogenesis in plants is given below:

(a) *Microsporogenesis* (*Formation of microspores*). During the developmental process of anthers the microsporocyte undergoes reductional division and four microspores or pollens (pollen grains) are formed. A pollen germinates on the stigma, and its nucleus divides by equational division into two nuclei; one nucleus, which is round in shape, is the tube nucleus and guides the development of pollen tube. The other one, somewhat elongated, and with dense cytoplasm, is the generative nucleus. This again divides into two nuclei which function as male gametes (sperms). The developmental phase represented by the pollen tube alongwith its three nuclei constitutes the male gametophyte (microgametophyte).

(b) *Megasporogenesis* (*Formation of megaspore*). One cell out of the nucellus tissue from within the ovule of an ovary (megaspore mother cell) enlarges in size to undergo reduction division (meiosis). The product of meiosis is four megaspores arranged in a linear order. The lower three megaspores which are small in size disintegrate and the fourth one increases in size to form the embryo sac, and develops into two; one moves to the micropylar end and the other to the chalazal end. There each nucleus undergoes mitotic divisions giving rise to four nuclei at each end. One nucleus each from the two ends moves towards the centre, where both of them fuse to form a 2n endospermic nucleus. The three nuclei on the chalazal end, called the antipodals, develop cell wall around them and in most plant species degenerate after fertilization. At the micropylar pole, the large-size central nucleus is the "egg" and the two lateral ones are the synergids. The egg functions as female gamete.

Fertilization

The pollen-tube pierces through the style of the gynaeceum and enters the ovule through the micropylar end. The pollen-tube ruptures and the two male gametes are released; one fertilizes the egg cell to form 2n embryo or the zygote and the second male gamete fuses with the endospermic nucleus. The 3n tissue forms the endosperm which serves as reserve food material. Since for the developing embryo the two male gametes released by the pollen-tube are used simultaneously in fertilization within the ovule, this process is called double fertilization.

PROBLEMS

1. Which part of the cell do you think is more important from genetic viewpoint and why?
2. Do you think that different plant organs have different chromosome number?
3. The somatic (2n) chromosome number of maize is 20. What is its gametic number? How many chromosomes are there in the pollen grain, the egg, the endosperm, the root tip, aleurone layer and testa?
4. What will happen to the chromosome number and the resulting gametes, if the second division fails to occur during the meiotic process in a common wheat plant?
5. How does the process of gamete formation in animals differ from that in plants?
6. In what way does the division of cytoplasm differ from that of the nucleoplasm in a plant cell undergoing meiosis?