LESSON 3

MEIOSIS. REPRODUCTION. GAMETOGENESIS.

Meiosis

The process of meiosis bears striking similarities to mitosis. Like mitosis, meiosis begins after a cell has progressed through the G1, S, and G2 phases of the cell cycle. However, meiosis involves two successive divisions rather than one (as in mitosis). Prior to meiosis, the chromosomes are replicated in S phase to produce pairs of sister chromatids. This single replication event is then followed by two sequential cell divisions called meiosis I and II. As in mitosis, each of these is subdivided into prophase, prometaphase, metaphase, anaphase, and telophase.

Prophase of meiosis I

This stage is further subdivided into stages known as *leptotene, zygotene, pachytene, diplotene,* and *diakinesis*.

<u>*Leptotene*</u>. The replicated threadlike chromosomes begin to condense.

<u>*Zygotene*</u>. A recognition process known as ***synapsis***, in which the homologous chromosomes recognize each other and begin to align themselves.

<u>*Pachytene*</u>. The homologs have become completely aligned. The associated chromatids are known as ***bivalents***. Each bivalent contains two pairs of sister chromatids (a total of four chromatids). In most eukaryotic species, a ***synaptonemal complex*** is formed between the homologous chromosomes. Prior to the pachytene stage, when synapsis is complete, an event known as ***crossing over*** usually occurs. Crossing over involves a physical exchange of chromosome pieces. The connection that results from crossing over is called a ***chiasma*** (plural: ***chiasmata***), because it physically resembles the Greek letter chi, χ.

<u>*Diplotene*</u>. The synaptonemal complex has largely disappeared. The bivalent pulls apart. A bivalent is also called a ***tetrad*** (from the prefix “tetra-,” meaning four) because it is composed of four chromatids.

<u>*Diakinesis*</u>. The synaptonemal complex completely disappears.

Figure 1 emphasizes some of the important events that occur during prophase of meiosis I.

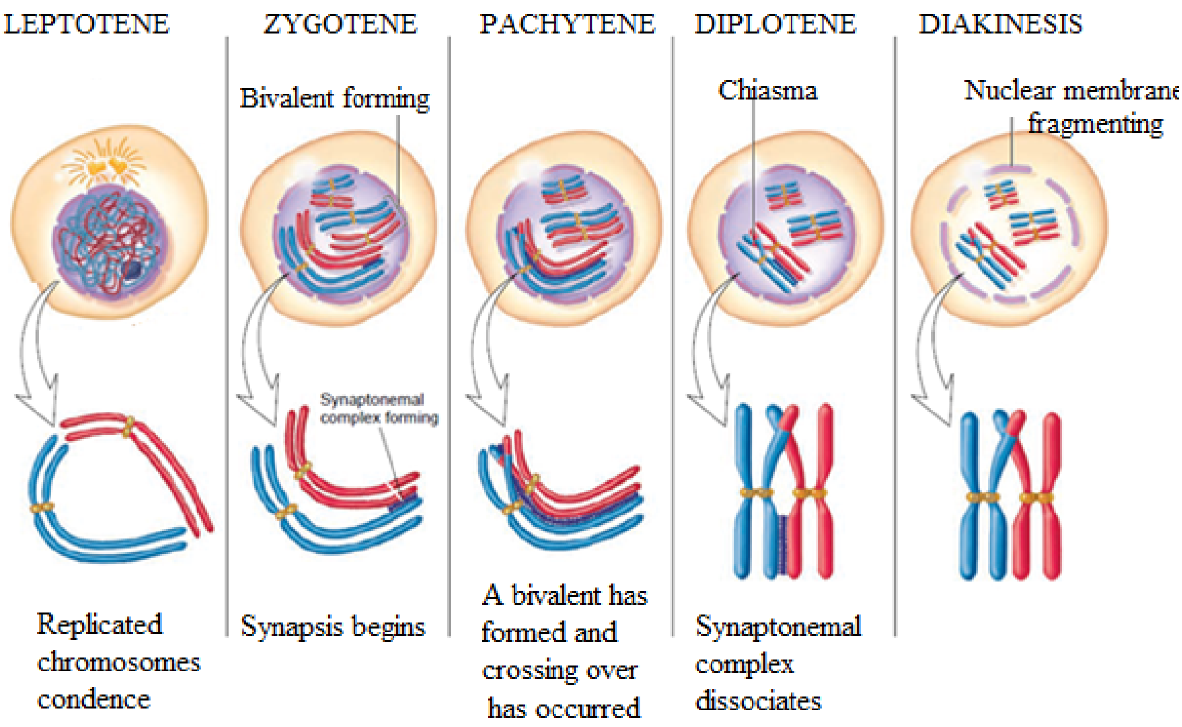


Fig. 1. Prophase of meiosis I

Prometaphase I

The spindle apparatus is complete, and the chromatids are attached via kinetochore microtubules.

Metaphase I

The bivalents are organized along the metaphase plate. The paired chromosomes orient toward opposite poles of the spindle.

Anaphase I

The two pairs of sister chromatids within a bivalent separate from each other. However, the connection that holds sister chromatids together does not break. Instead, each joined pair of chromatids migrates to one pole, and the homologous pair of chromatids moves to the opposite pole.

Telophase I

The sister chromatids have reached their respective poles, and decondensation occurs (in many, but not all, species). The nuclear membrane may re-form to produce two separate nuclei.

The meiosis I is a ***reduction*** division. The original diploid cell had its chromosomes in homologous pairs, but the two cells produced at the end of meiosis I are considered to be haploid; they do not have pairs of homologous chromosomes.

The meiosis II is a ***equational*** division.

Prophase II

The chromosomes condense and become attached to a new spindle apparatus.

Metaphase II

The chromosomes move to positions in the equatorial plane of the cell.

Anaphase II

The centromeres of chromosomes split to allow the constituent sister chromatids to move to opposite poles (a phenomenon is called chromatid disjunction).

Telophase II

The separated chromatids — now called chromosomes — gather at the poles and daughter nuclei form around them. Each daughter nucleus contains a haploid set of chromosomes.

Figure 2 emphasizes the events that occur during meiosis II.

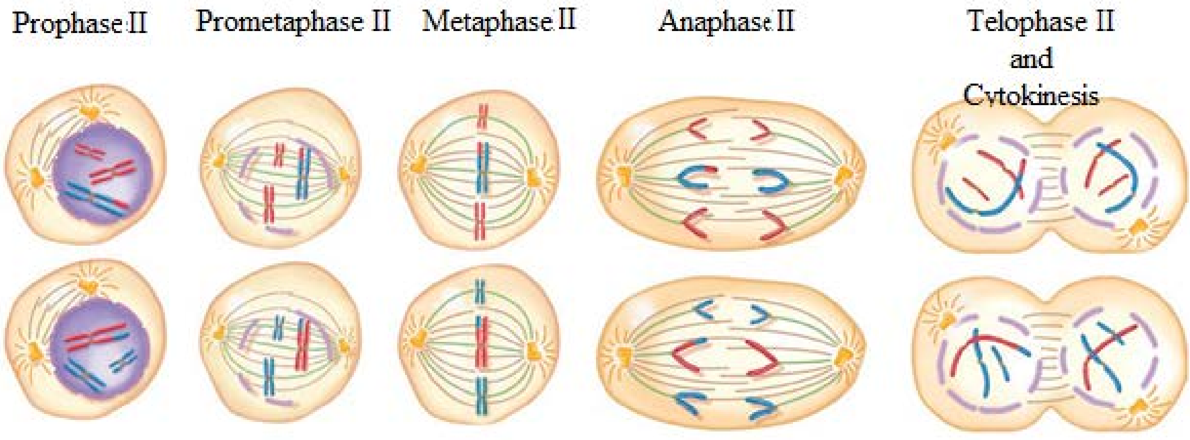


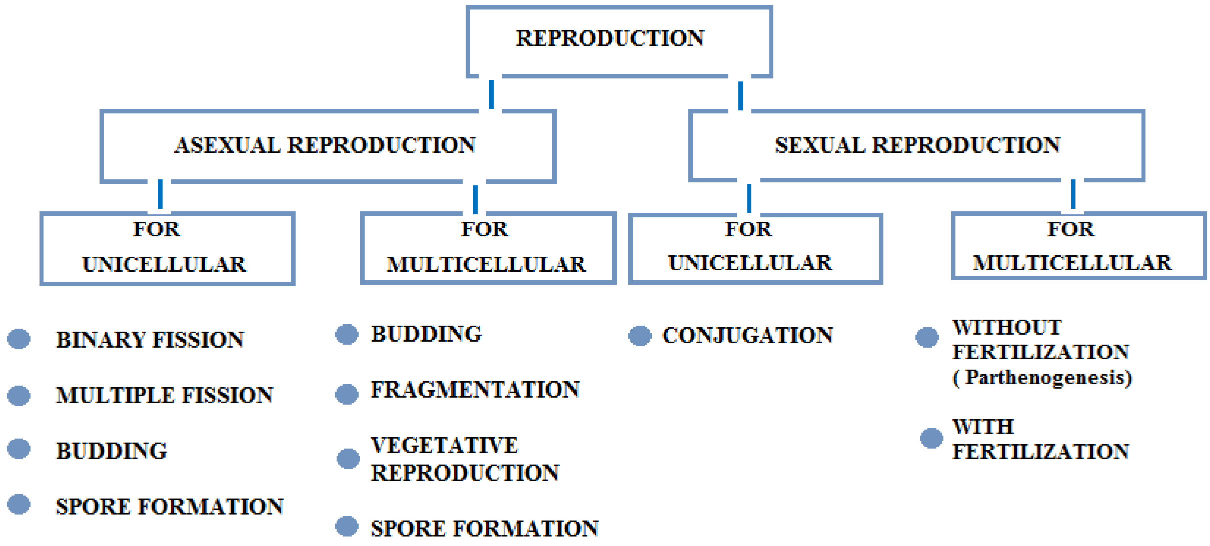
Fig. 2. The events of meiosis II

<u>The outcomes and biological significance of Meiosis:</u>

- ✓ To ensure the production of haploid cells (gamets).
- ✓ To maintain diploid number of chromosome in each generation.
- ✓ Through the shuffling of chromosomes (independent assortment) and chromosomal recombination (by means of crossing over), new sets of chromosomes with a mix of paternal and maternal chromosomes are created, generating diversity in gametes.

The sorting events that occur during meiosis II are similar to those that occur during mitosis, but never the less both processes have much more differeces.

Reproduction is the biological process by which new individual organisms – "offspring" – are produced from their "parents". Reproduction is a fundamental feature of life; each individual organism exists as the result of reproduction. There are two forms of reproduction: asexualand and sexual.



Asexual reproduction is a type of reproduction by which offspring arise from a single organism.

Asexual reproduction is the primary form of reproduction for single-celled organism as the archaea, bacteria, and protists. Many plants and fungi reproduce asexually as well.

<u>Types of Asexual Reproduction for unicellular organisms:</u>

Binary fission

It is the simplest and most common method of asexual reproduction. The whole parental body acts as the reproductive unit. The nucleus of the unicellular parent organism divides into two. This is followed by the division of the cytoplasm and 2 daughter cells of almost equal size are formed. Only prokaryotes (archaea and bacteria) reproduce asexually through binary fission. Eukaryotes (such as protists and unicellular fungi) reproduce by mitosis.

Based on the plane of cytoplasmic division binary fission is of 3 types:

Simple (irregular) binary fission. The cytoplasmic division passes through any plane (fig.3 (a)). <u>Example</u>: Amoeba.

Transverse binary fission. The plane of cytoplasmic division coincides with the transverse axis of the individual (fig.3(b)). Example: Paramoecium, Planaria.

Longitudinal binary fission. The plane of cytoplasmic division coincides with the longitudinal axis of the individual (fig.3 (c)). Example: Euglena.

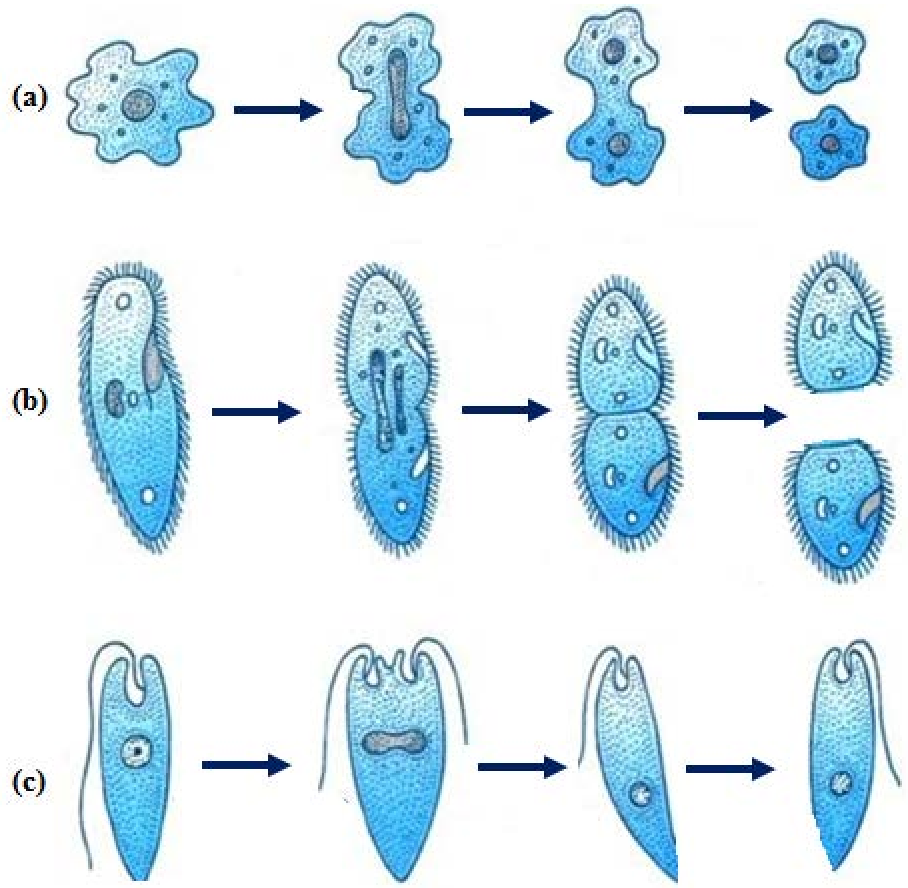


Fig. 3 . Scheme of Binary fission:

(a) Simple (irregular) fission, (b) Transverse fission, (c) Longitudinal fission

Multiple fission

In some organisms the nucleus of the parent divides into many daughter nuclei by repeated divisions (amitosis). This is followed by the division of the cytoplasm into several parts with each part enclosing one nucleus. So a number of daughter cells are formed from a single parent at the same time. Example: Plasmodium (malarial parasite).

Budding

Some cells divide asymmetrically by budding. This process results in a 'mother' cell and a smaller 'daughter' cell. Example: baker's yeast.

Internal budding (Endodyogeny, endogony) involves an unusual process in which two daughter cells are produced inside a mother cell, which is then consumed by the offspring prior to their separation. Example: Toxoplasma gondii.

Spore formation

A mode of reproduction resembling multiple fission in which organism breaks up into a number of pieces, or spores, each of which eventually develops into an organism like the parent form. Example: Some Protozoans.

Types of Asexual Reproduction for unicellular organisms:

Budding

Budding is a form of asexual reproduction in which a new organism develops from an outgrowth or bud due to cell division at one particular site. The new organism remains attached as it grows, separating from the parent organism only when it is mature, leaving behind scar tissue (fig.4). Since the reproduction is asexual, the newly created organism is a clone and is genetically identical to the parent organism. Example: hydra, sponges.

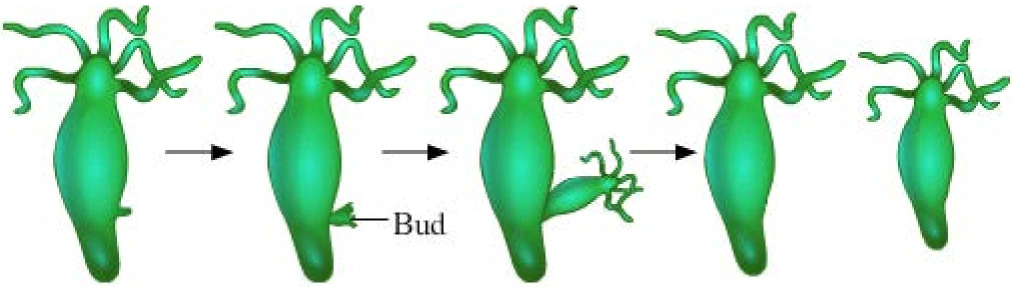


Fig. 4. Scheme of Budding in Hydra

Fragmentation

Fragmentation is a form of asexual reproduction where a new organism grows from a fragment of the parent. Each fragment develops into a mature, fully grown individual. Example: some Planarian and Annelid worms, Turbellarians, sea stars, fungi and plants (fig.5).

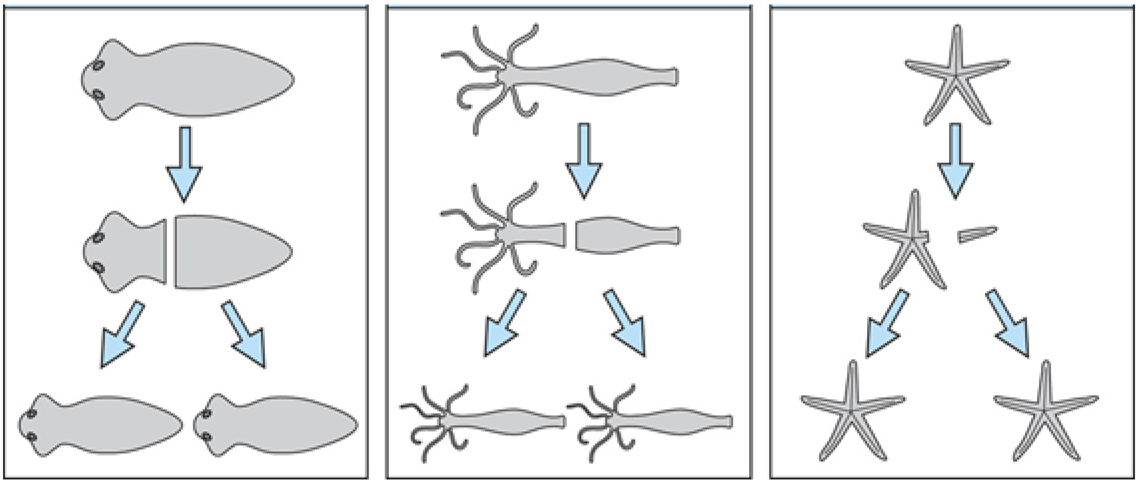


Fig. 5. Scheme of fragmentation in Planaria (a), Hydra (b), Sea star (c)

Vegetative reproduction

Vegetative reproduction is a type of asexual reproduction found in plants where new individuals are formed without the production of seeds or spores by meiosis or syngamy. Examples: common in plants.

Spore formation

Some organisms can utilize true asexual spore formation, which involves mitosis giving rise to reproductive cells called mitospores that develop into a new organism after dispersal. Example: conidial fungi, red algae.

Sexual reproduction is a form of reproduction where two morphologically distinct types of specialized reproductive cells called gametes fuse together. In the first stage of sexual reproduction, "meiosis", the number of chromosomes is reduced from a diploid number (2n) to a haploid number (n). During "fertilization", haploid gametes come together to form a diploid zygote and the original number of chromosomes is restored.

Types of Sexual Reproduction for unicellular organisms:

Conjugation

It involves temporary pairing of two parents, called conjugant, to exchange their genetic materials (male pronucleus). It is found in ciliate protozoans e.g., *Paramecium*. Steps of conjugation are shown at figure 6.

(1) Two paramecium of opposite mating types come in contact.

(2) Pellicle and ectoplasm at the point of contact degenerate to form a cytoplasmic bridge.

(3) Macronucleus disappears. Micronucleus divides unequally to produce smaller male pronucleus and larger female pronucleus, but they are genetically identical. Male pronucleus is active and migratory whereas female pronucleus is inactive and stationary.

(4) Male pronucleus of each conjugant cross the cytoplasmic bridge and fused with female pronucleus to form diploid zygote nucleus.

(5) After the exchange of genetic material, the paramecia separate. Cytoplasmic bridge breaks down.

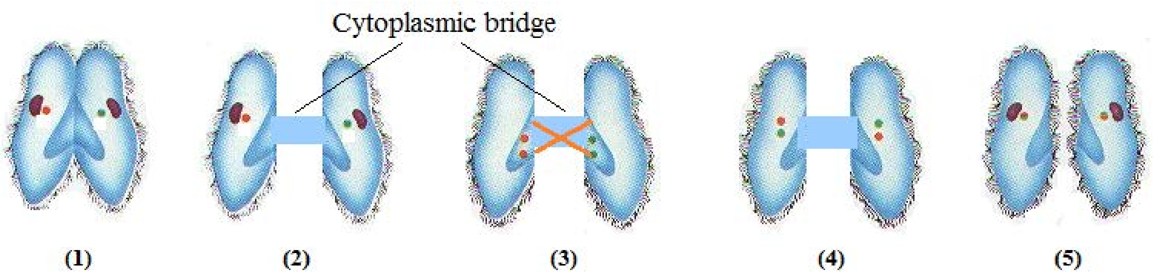


Fig. 6. Steps of conjugation in Paramecium

Syngamy

It is way of sexual reproduction in which the two individuals obtain the sex differences that is became the gametes and then fuse to form a zygote. Based on structure of fusing gametes, syngamy is of following types:

Isogamy is a form of syngamy that involves gametes of similar morphology (similar shape and size) (fig.7 a).

Anisogamy (also called heterogamy) is the form of syngamy that involves the union or fusion of two gametes, which differ in size and/or form (fig.7 b).

Oogamy. It is a form of anisogamy (heterogamy) in which the female gamete (e.g. egg cell) is significantly larger than the male gamete and is non-motile. The male gametes are typically highly mobile spermatozoa (fig.7 c).

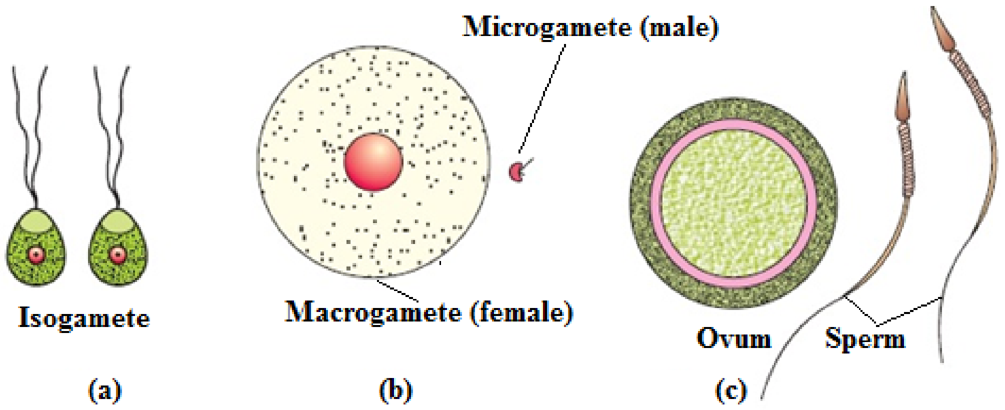


Fig. 7. Types of gametes

Isogamy (a), Anisogamy (b), Oogamy (c)

<u>Types of Sexual Reproduction for multicellular organisms:</u>

Parthenogenesis

Parthenogenesis is a natural form of reproduction in which growth and development of embryos occur without fertilization. In animals, parthenogenesis means development of an embryo from an unfertilized egg (from Greek “virgin birth”.

Parthenogenesis can occur without meiosis through mitotic oogenesis. Mitotic divisions produce mature egg cells, and these cells directly develop into embryos. Parthenogenesis involving meiosis is more complicated. In some cases, the offspring are haploid (e.g., male ants). In other cases, the ploidy is restored to diploidy by various means. This is because haploid individuals are not viable in most species.

Parthenogenesis occurs naturally in many plants, some invertebrate animal species (including nematodes, water fleas, some scorpions, aphids, some bees, some parasitic wasps) and a few vertebrates (such as some fish, amphibians, reptiles and very rarely birds). This type of reproduction has been induced artificially in a few species including fish and amphibians.

Facultative parthenogenesis - is the process in which a female can produce offspring either sexually or via asexual reproduction. Facultative parthenogenesis is extremely rare in nature, with only a few examples of animal taxa capable of facultative parthenogenesis: male bees, wasps, and ants develop from unfertilized eggs. Facultative parthenogenesis is believed to be a response to a lack of a viable male. A female may undergo facultative parthenogenesis if a male is absent from the habitat or if it is unable to produce viable offspring.

Obligate parthenogenesis is the process in which organisms exclusively reproduce through asexual means. A female will produce an ovum with a full set (two sets of genes) provided solely by the mother. Thus, a male is not needed to provide sperm to fertilize the egg. This form of asexual reproduction is thought in some cases to be a serious threat to biodiversity for the subsequent lack of gene variation and potentially decreased fitness of the offspring. Many species that rely on obligate parthenogenesis as their major method of reproduction. For example: salamanders, some lizards, snakes, turkeys, roundworms, flatworms and so on.

Parthenogenesis in Mammals

Mammalian parthenogenesis are less successful. A mouse embryo derived from an activated oocyte shrivels up and ceases developing. In humans, if an oocyte somehow doubles its genetic material and starts to develop, an embryo does not form at all, but a tumor like mass called a teratoma is formed. If a sperm doubles its DNA and divides, it forms a different type of abnormal growth. Nevertheless, biologists thought it might be possible for a mammal to be a partial parthenogenesis — that is, part of the body is derived from an unfertilized maternal cell.

Sexual reproduction is a common way for eukaryotic organisms to produce offspring. During sexual reproduction, germ line cells known as ***gametes*** are formed. Gametes are typically *haploid***,** which means they contain half the number of chromosomes as diploid cells. Haploid cells are represented by 1*n* and diploid cells by 2*n*, where *n* refers to a set of chromosomes (for example, a diploid human cell contains 46 chromosomes, but a gamete (sperm or egg cell) contains only 23 chromosomes). The formation of gametes is called ***gametogenesis***. It occurs in the gonads of each sex. *Oogenesis*, the formation of eggs, occurs in the ovaries and *spermatogenesis*, the formation of sperm, occurs in the testes.

Spermatogenesis

This process includes four stages:

1. Multiplication

2. Growth
3. Maturation
4. Differentiation

Spermatogenesis begins in the male testes in germ cells known as ***spermatogonia*** that undergo numerous mitotic divisions. Some of these cells remain a spermatogonial, and the other cell becomes a diploid ***primary spermatocyte*** (2n2c). Primary spermatocytes (2n4c after prophase I) undergo a symmetrical meiosis I, producing two ***secondary spermatocytes*** (1n2c), each of which undergoes a symmetrical meiosis II. At the conclusion of meiosis, each original primary spermatocyte thus yields four equivalent haploid ***spermatids*** (1n1c). These spermatids then mature by developing a characteristic whiplike tail and by concentrating all their chromosomal material in a head, thereby becoming functional ***sperm*** (fig.8). The meiotic divisions allowing conversion of primary spermatocytes to spermatids begin only at puberty, but meiosis then continues throughout a man's life. The entire process of spermatogenesis takes about 48–60 days: 16–20 for meiosis I, 16–20 for meiosis II, and 16–20 for the maturation of spermatids into fully functional sperm. Within each testis after puberty, millions of sperm are always in production, and a single ejaculate can contain up to 300 million. Over a lifetime, a man can produce billions of sperm, almost equally divided between those bearing an X and those bearing a Y chromosome.

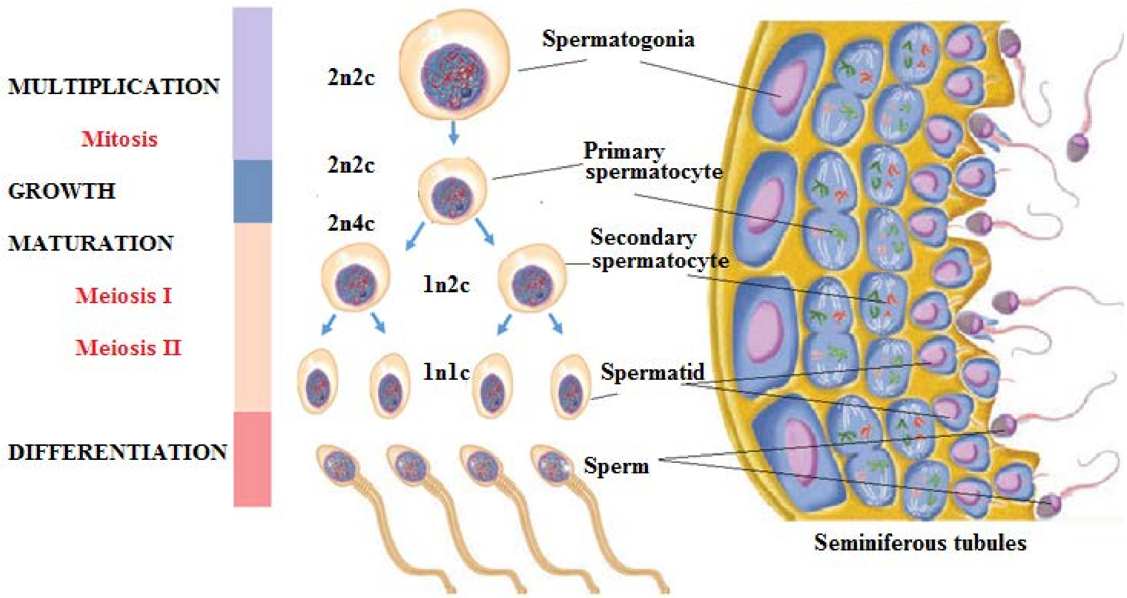


Fig. 8. Stages of Spermatogenesis

Structure of a sperm

The structure of a sperm cell includes a head, neck and tail (fig.9). The head of the sperm contains a haploid nucleus and an organelle at its tip, known as an acrosome. The acrosome contains digestive enzymes that are released when a sperm meets an egg cell. These enzymes enable the sperm to penetrate the outer protective layers of the egg and gain entry into the egg cell’s cytosol.

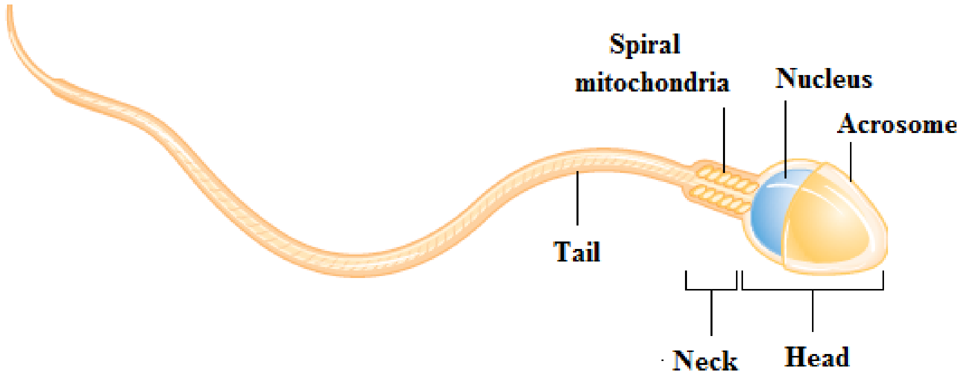


Fig. 9. Structure of sperm

Oogenesis

This process includes three stages (fig.10):

1. Multiplication
2. Growth
3. Maturation

Oogenesis begins in the fetus when diploid germ cells in the ovary, called ***oogonia*** (singular, *oogonium*) (2n2c), multiply rapidly by mitosis and initiate meiosis to produce a large number of ***primary oocytes*** (2n4c). By six months after conception, the fetal ovaries are fully formed and contain about half a million primary oocytes arrested in the diplotene of meiosis I. These cells, with their homologous chromosomes locked in synapsis, are the only oocytes the female will produce, so a girl is born with all the oocytes she will ever possess. In humans, approximately 1 million primary oocytes per ovary are produced before birth.

From the onset of puberty, at about age 12, until menopause, some 35–40 years later, most women release one primary oocyte each month (from alternate ovaries), amounting to roughly 480 oocytes released during the reproductive years.

For each primary oocyte, meiosis I results in the formation of two daughter cells that differ in size, so this division is asymmetric. The larger of these cells, the ***secondary oocyte*** (1n2c***)*** receives over 95% of the cytoplasm. The other small sister cell is known as the *first polar body.* The first polar body usually arrests its development and does not undergo the second meiotic division. However, the first polar body does divide in a small proportion of cases, producing two haploid polar bodies. The two (or rarely, three) small polar bodies apparently serve no function and disintegrate, leaving one large haploid ovum as the functional gamete.

MULTIPLICATION	GROWTH	MATURATION
Mitosis (occurs in fetal ovary) Meiosis I starts but stops at *diplotene* of Prophase I	Arrest at diplotene of meiosis I. Oocyte grows and accumulates nutrients.	Meiosis I: Asymmetrical division (completed at ovulation) Meiosis II: Asymmetrical division (occurs only after fertilization)

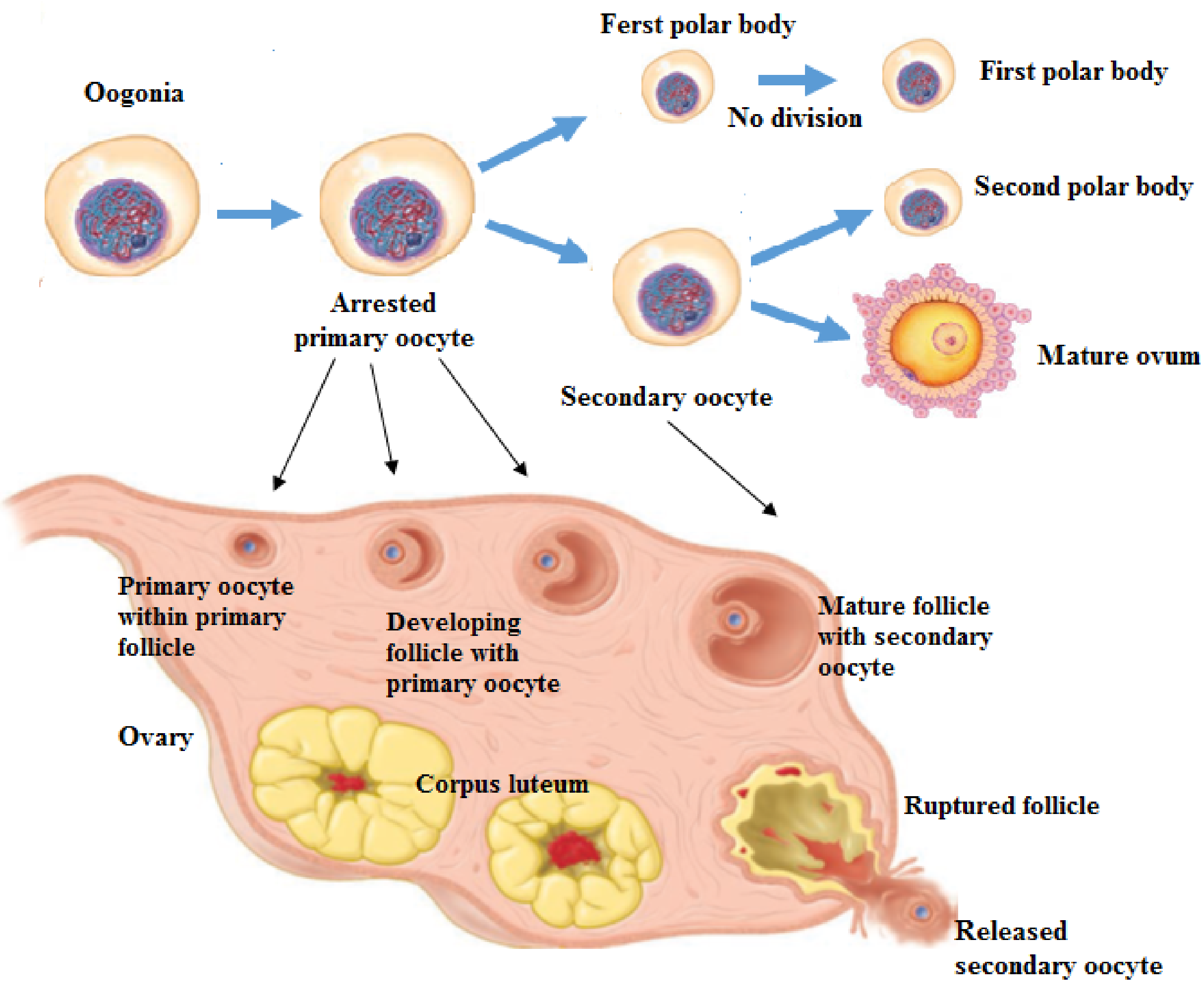


Fig. 10. Stages of Oogenesis

Thus, only one of the three (or rarely, four) products of a single meiosis serves as a female gamete. The secondary oocyte then begins meiosis II. In mammals, the secondary oocyte is released from the ovary at metaphase of meiosis II — an event called ovulation— and travels down the oviduct toward the uterus. During this journey, if a sperm cell penetrates the secondary oocyte, it is stimulated to complete meiosis II; the secondary oocyte produces a haploid ***ovum*** (1n1c) and a *second polar body*. The haploid ovum and sperm nuclei then unite to create the diploid nucleus of a new individual.

The product of egg formation in humans is a large, nutrient-rich ovum whose stored resources can sustain the early embryo (fig.11).

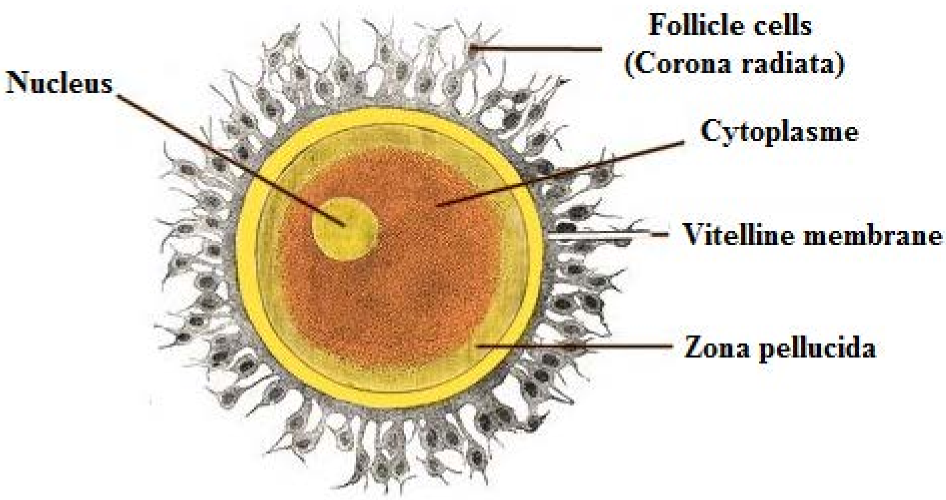


Fig. 11. Structure of ovum

Types of ovum (egg)

There are some types of ovum. The type of ovum defines the following development – the certain way of subsequent cleavage. The *polarity* is one of the characteristic of ovum. The polarity means that an ovum has two poles: *vegetal* and *animal*. The pole of the egg with the highest concentration of yolk is referred to as the vegetal pole while the opposite is referred to as the animal pole.

Eggs classified according to the amount or distribution of yolk (tabl.1).

Table 1

Classification of eggs

Type of ovum	***Characteristic***	***Example***
According to the amount of yolk		
Alecithal	Without yolk	Mammals
Oligolecithal	Small amount	Amphioxus
Mesolecithal	Moderate amount	Amphibians
Polylecithal	Large amount	Birds
According to distribution of yolk		
Homolecithal	The yolk equally distributed throughout the cytoplasm	Amphioxus
Centrolecithal	The yolk in the center of the cytoplasm	Arthropods
Telolecithal	The uneven distribution of yolk in the cytoplasm. The yolk is concentrated at one pole of the egg separate from the developing embryo.	Birds, Reptiles, Fish,
Isolecithal	The small amounts of yolk evenly distributed throughout the cytoplasm.	Mammals

Some differences between Spermatogenesis and Oogenesis are shown in a table 2.

Table 2

Differences between Spermatogenesis and Oogenesis

Spermatogenesis	***Oogenesis***
4 stages: Multiplication Growth Maturation Differentiation	3 stages: Multiplication Growth Maturation
Process occurs in seminiferous tubules of testes	Multiplication, Growth, Maturation (partially) occur in the ovary; Maturation completes in Fallopian tubes.
Both meiotic divisions occur in sequence	I Meiosis stops at Diplotene; II Meiosis stops at metaphase.
Four sperms from one spermatogonia	Only one ovum from one oogonium
A man can produce billions of sperm over a lifetime	Only 480 oocytes released during the reproductive years