Chapter -1

Reproduction in organisms.

Reproduction is a biological process in which an organism gives rise to young ones (offspring) similar to itself. The offspring grow, mature and in turn produce new offspring. Thus, there is a cycle of birth, growth and death. Reproduction enables the continuity of the species, generation after generation.

Types of reproduction

1. Asexual reproduction.
2. Sexual reproduction.

Asexual reproduction -In this method, a single individual (parent) is capable of producing offspring. As a result, the offspring that are produced are not only identical to one another but are also exact copies of their parent. The term clone is used to describe such morphologically and genetically similar individuals.

Asexual reproduction is common among single-celled organisms, and in plants and animals with relatively simple organisations. In Protists and Monerans, the organism or the parent cell divides by mitosis into two to give rise to new individuals. Thus, in these organisms cell division is itself a mode of reproduction.

Types of Asexual reproduction

a. Binary fission
b. Budding
c. Encystations & Sporulation.

a . Binary fission - Many single-celled organisms reproduce by binary fission, where a cell divides into two halves and each rapidly grows into an adult (e.g., Amoeba, Paramecium).

b. Budding - In yeast, the division is unequal and small buds are produced that remain attached initially to the parent cell which, eventually gets separated and mature into new yeast organisms (cells).3

c. Encystations & Sporulation-Under unfavourable condition the Amoeba withdraws its pseudopodia and secretes a three-layered hard covering or cyst around itself. This phenomenon is termed as **encystations.** When favourable conditions return, the encysted Amoeba divides by multiple fission and produces many minute amoeba or **pseudopodiospores**; the cyst wall bursts out, and the spores are liberated in the surrounding medium to grow up into many amoebae. This phenomenon is known as **sporulation.**

Formation of specialized structures - 1. Conidia − (Example: Penicillium) 2. Gemmules − (Example: Sponges) 3.Buds − (Example: Hydra) 4.Zoospores − Microscopic, motile spores (Example: Algae)

Vegetative propagation − It means of asexual reproduction in plants. Different structures are capable of giving rise to new plants. A. Runner − (Example: Gladiolus) B. Rhizome − (Example: Ginger) C. Sucker D. Tuber − (Example: Potato) E. Offset F. Bulb − (Example: Onion).

Sexual Reproduction: Pre-Fertilisation Events

● Sexual reproduction involves the formation of the male and female gametes in either the same individual or two individuals. These gametes fuse to form a zygote, which develops into a new individual.

● Offspring are not identical to each other or to the parents. So, sexual reproduction gives rise to diversity among living organisms.

● All organisms pass through two stages. ○ Juvenile phase − Period of growth; non reproductive ○ Vegetative phase or reproductive phase

● In non-primate mammals like rats, sheep, dogs, cows and tigers, the cyclic change in the activities of the ovaries and the oviduct is called the oestrus cycle; in primates like monkeys, apes and humans, it is called the menstrual cycle.

● Certain mammals are called continuous breeders since they can reproduce throughout their reproductive phase, while some are called seasonal breeders since they can reproduce only in the favourable seasons.

Events in Sexual Reproduction

● Organisms reproducing sexually exhibit certain events. These are:

○ Pre-fertilisation events ○ Fertilisation events ○ Post-fertilisation events

Pre-Fertilisation Events

● Events taking place before the fusion of the gametes Consist of: ○ Gametogenesis ○ Gamete transfer

Gametogenesis

● Process of formation of gametes (male and female)

● Gametes are haploid

● In some organisms (like algae), they are almost similar (homo or isogametes), and cannot be categorised as male and female gametes.

● In others, the two gametes are morphologically and physiologically different (heterogametes), and are of two types—antherozoid or sperm (male gamete) and egg or ovum (female gamete).

● In some organisms both the sexes are present in the same individual (monoecious or homothallic), and in others, they are present in two individuals (dioecious or heterothallic). In a unisexual flower, the male flower is called staminate and the female flower is called pistillate.

● Gamete formation takes place by cell division.

In haploid parents, it is by mitosis; in diploid parents, it is by meiosis, with specialised cells called meiocytes undergoing meiosis. .

Gamete Transfer

● For their fusion to take place, the gametes need to be transferred.

● In most organisms, the male gametes are motile, while the female gametes are non-motile, and the male gametes need a medium for their movement. A large number of male gametes do not make it to the female gamete, and hence, several thousands of male gametes are produced to overcome this loss.

● In angiosperms, the pollen grain carries the male gamete and the ovule carries the female gamete.

● Pollen grains are produced in the anther and need to be transferred to the stigma for fertilisation to occur. This is easy in monoecious plants as both the anther and the

stigma are present close by; in dioecious plants, it takes place by pollination.

Fertilisation Events

● Fertilisation is the most important event in sexual reproduction.

● This process is also called syngamy and leads to the formation of the zygote.

● However, in some organisms, zygote formation takes place without fertilisation, and is known as parthenogenesis (occurs in rotifers, honeybees and some lizards).

● In most aquatic organisms and amphibians, fertilisation takes place outside their body (in the water), and is termed as external fertilization.Their eggs and offspring are highly vulnerable to predators and this threatens their survival up to adulthood.

● In most terrestrial organisms, fertilisation is internal, i.e., it takes place inside the female body. In this process, the male gamete is motile and reaches the female gamete to fuse with it, thereby forming zygote. Male gametes are produced in large numbers.

Post-Fertilisation Events

● Events taking place after fertilisation are called post- fertilisation events. Zygote

● The haploid gametes fuse to form a diploid zygote in all organisms.

● In external fertilisation, a zygote is formed in an external medium, and in internal fertilisation, a zygote is formed inside the individual.

● The development of a zygote depends upon the life cycle of an organism and its surroundings. In some organisms, the zygote does not develop immediately, and develops a thick wall around itself. This wall is resistant to damage and desiccation.

Embryogenesis

● It is the process of development of the embryo from the zygote.

● The zygote undergoes cell division and differentiation.

● Cell division increases the number of cells of the embryo, and cell differentiation helps the cells undergo modifications to form specialised tissues and organs.

● Animals can be grouped into two categories based on how and where the development of the zygote takes place. These categories are:

○ **Oviparous** − The fertilised egg is covered by a calcareous shell and is released into the outside environment. The development takes place inside the egg and the young one hatches out (example: birds and reptiles).

○ **Viviparous** − The development of the zygote takes place inside the female body, and the developed young one is delivered outside (example: mammals, including humans).

● In flowering plants, the zygote is formed inside the ovule.

○ Zygote → Develops into → Embryo ○ Ovule → Develops into → Seed

○ Ovary → Develops into → Fruit → Contains → Seeds → Disperse and germinate to form new plants

Cheapter -2

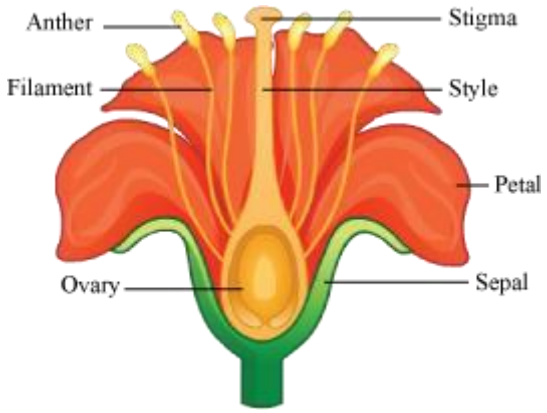
Sexual Reproduction in Flowering Plants

Pre-Fertilisation Events

- Several hormonal and structural changes result inthe development of a flower.
- Inflorescences bear the flower buds, and then the flowers.
- Flowers are the reproductive parts of a plant.

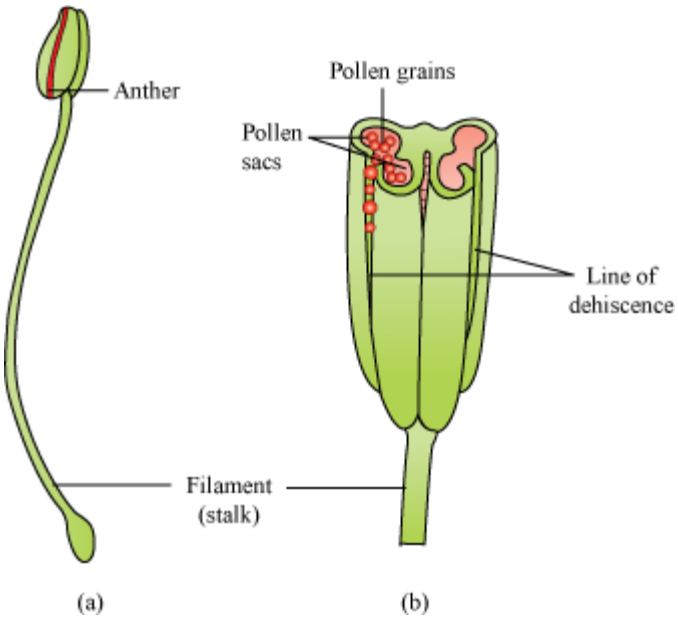
- In the flowers, the androecium (male reproductive part)and the gynoecium (female reproductive part) develop.

Androecium

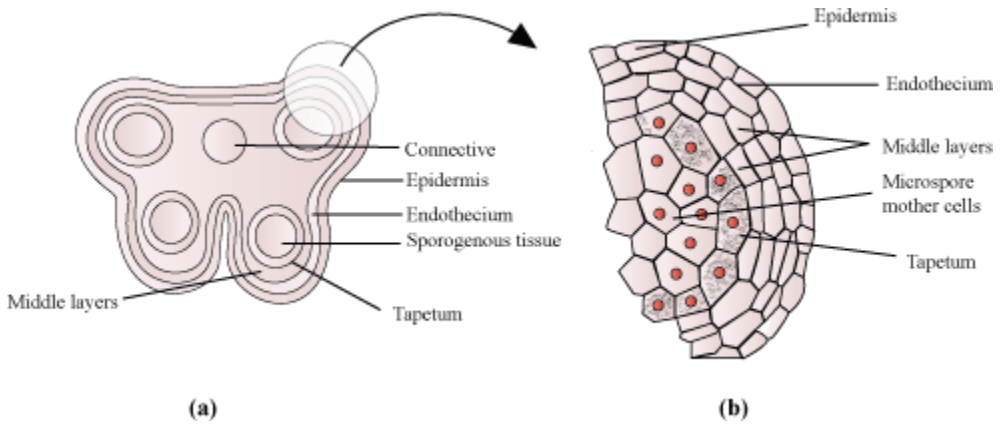


- The androecium consists of whorls of stamen.
- The stamen consists of the **filament** (long and slender stalk) and **anther** (bilobed structure).
- Filament is attached to the thalamus or to the petal.
- **Anther**:
    - A typical anther is bilobed and each lobe is dithecous (consists of two theca).
    - Theca are separated by a longitudinal groove running lengthwise.
    - The microsporangia are located at the corners, two in each theca. They further develop to form pollen sacs, which contain the pollen grains.
    - The microsporangia are located at the corners, two in each theca. They further develop to form pollen sacs, which contain the pollen grains.

- **Structure of microsporangium**



- The microsporangium is surrounded by four wall layers (epidermis, endothecium, middle layers, andtapetum).
- The outer three layers are protective and help in dehiscence of anther to release the pollen grains. The tapetum provides nourishment to the developingpollen grains.
- In the young anther, the sporogenous tissue formsthe centre of each microsporangium.



Microsporogenesis

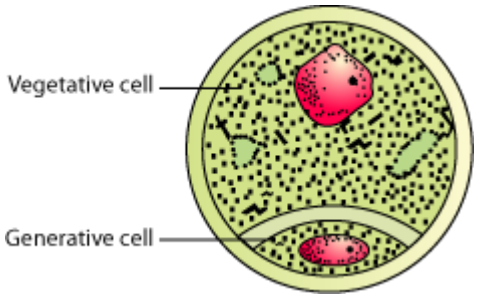
- It is the process of formation of microspore from PMC (Pollen Mother Cells).
- As development occurs in the anther, thesporogenous tissue undergoes meiosis to form

microspore tetrad.

- Each cell of sporogenous tissue has capacity to give rise to a tetrad. Hence, each cell is a potential pollen or PMC.
- As the anther matures, the microspores get detached from each other and develop into pollen grains.

Pollen grains

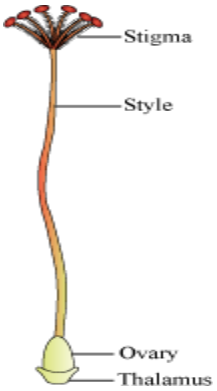
- Represent the male gamete and are spherical, having a two- layered wall:
  - Exine (outer) − Hard layer made of sporopollenin, which is extremely resistant and can withstand high temperatures, acidic and alkaline conditions, and enzymes
  - Intine (inner) − Thin and continuous layer made up of cellulose and pectin
- Mature pollen grain contains two cells:
  - Vegetative cell − Large with irregular nucleus, contains food reserves
  - Generative cell − Small and floats in the cytoplasm of the vegetative cell .



- In 60% of the angiosperms, pollen grains are shed at 2- celled stage while in others generative cell undergoes mitosis to form two male gametes (3-celled stage).
- The viability of pollen grains after they are shed depends upon temperature and humidity. It ranges from 30 minutes to few months.

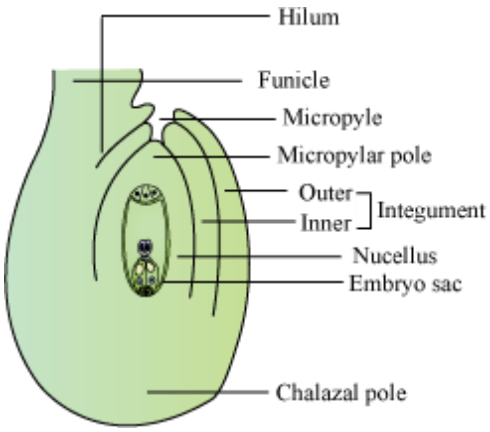
Gynoecium and Formation of Female Gametophyte

- The gynoecium represents the female reproductive part of a flower.
- It may be mono-carpellary (one pistil) or multi-carpellary (many pistils). In multi-carpellary, the pistils may be fused in one (syncarpous) or free (apocarpous).
- Each pistil consists of:
  - **Stigma** − Receives the pollen grains
  - **Style** − Elongated, slender part below the stigma
  - **Ovary**− Bulged basal part containing the placenta, which is located inside the ovarian locule (cavity)
  - The placenta contains the megasporangia or ovules.



Megasporangium

- The ovule is attached to the placenta by the **funicle**. The junction of the ovule and the funicle is called **hilum**.
- Each ovule has one or two protective layers, called **integuments**, which cover the rest of the ovule, except for a small opening called **micropyle**.
- The **chalaza** lying on the opposite side of the micropyle end represents the basal part of the ovule.
- **Nucellus** is present within the integuments and contains reserved food. The **embryo sac** or female gametophyte is located within the nucellus.



Megasporogenesis

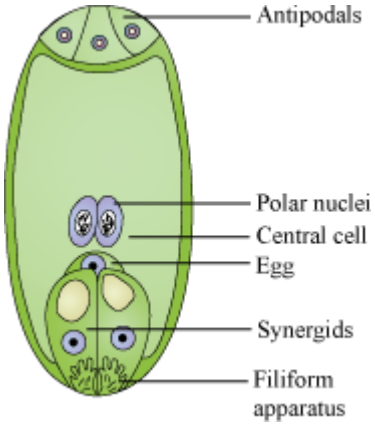
- The **megaspore mother cell** (MMC) gets converted into megaspores by the process of megasporogenesis.
- The MMC is large and contains a dense cytoplasm and a prominent nucleus. It undergoes meiosis to produce four megaspores.

Female Gametophyte

- In most flowering plants, only one megaspore is functional while the other three degenerate.
- The single functional megaspore develops into the female gametophyte. This kind of development is called monosporic development.
- The nucleus of the functional megaspore divides mitotically to form 2 nuclei, which move towards the opposite ends, forming a 2-nucleate embryo sac. Two more mitotic divisions ensue, leading to the formation of 4-nucleate and 8-nucleate embryo sacs.

- After the 8-nucleate stage, the cell walls are laid down and the typical female gametophyte (embryo sac) gets organised.
- Six of the 8-nuclei get surrounded by the cell wall and the remaining two, called **polar nuclei**, are situated below the egg apparatus in the large **central cell**.
- Three of the six cells are placed at the micropylar end and constitute the **egg apparatus** (2 **synergids** + 1 **egg cell**).
- The synergids have special thickenings at the micropylar end. These are together called the **filiform apparatus**. It helps in leading the pollen tubes into the synergids.
- Three cells are at the chalazal end, and are called **antipodal cells**.
- A typical angiosperm female gametophyte is 7-celled and 8- nucleated at maturity.

Pollination



Pollination

- It is the process of transfer of pollen grains from the anther to the stigma.
  Depending on the source of pollen, pollination can be divided as follows:
  - **Autogamy** − It is the transfer of pollen grains from the anther to the stigma of the same flower. Autogamy requires the anther and the stigma to lie close. It also requires synchrony in the pollen release and stigma receptivity.
    Plants like *Viola*, *Oxalis*, etc., produce two kinds of flowers—**chasmogamous flowers** (with exposed anther and stigma) and **cleistogamous flowers** (which do not open at all and only autogamy occurs).

    Geitonogamy − It is the transfer of pollens from the anther of one flower to the stigma of another flower in the same plant. Genetically, it is similar to autogamy, but it requires pollinating agents.
  - **Xenogamy** − It is the transfer of pollen grains from the anther to the stigma of a different plant. Pollination causes genetically different types of pollens to be brought to a plant.

Agents of Pollination

- Plants use air, water (abiotic agents) and animals (biotic agents) for pollination.
- **Pollination by wind**

- It is the most common form of abiotic pollination.
- Plants possess well-exposed stamens and large, feathery stigma.
- Pollens should be light and non-sticky to be carried easily by winds.
- Wind-pollinated flowers often have single ovule in the ovary and numerous flowers packed in an inflorescence.
- It is common in grass.

- **Pollination by water**
  - It is rare in flowering plants, except for some aquatic plants like *Vallisneria* and *Hydrilla*.
  - In most water-pollinated plants, the pollen grains are long and ribbon-like, and are protected from wetting by mucilaginous covering.
  - In a majority of water plants like water hyacinth and water lily, flowers emerge above the water level and are pollinated by insects.

- **Pollination by animals**
  - Majority of flowering plants use butterflies, bees, wasps etc., for pollination.
  - Most of the insect-pollinated flowers are large, colourful, fragrant, and contain nectar to attract the animal pollinators. These are called floral rewards.
  - Floral reward can be in the form of providing safe places to lay eggs (example: the tallest flower, *Amorphophallus*)
  - A symbiotic relationship exists between the plant, *Yucca* and its pollinator moth. The moth is dependent on the plant since the moth deposits its eggs in the locule of the ovary of the plant, and in return, the plant is pollinated by the moth.
  - The pollen grains are sticky and get stuck to the body of the pollinator.

Out Breeding Devices

- Repeated self pollination leads to inbreeding depression.
- Plants have developed methods to prevent self pollination. Autogamy is prevented by following ways:
  - Pollen release and stigma receptivity not coordinated
  - Different positioning of the anther and the stigma
  - Production of unisexual flowers
- Ways to prevent both autogamy and geitonogamy:
  - Presence of male and female flowers on different plants, such that each plant is either male or female (dioecy).
  - This mechanism is present in several species of papaya.

Pollen−Pistil Interactions

- Pollination does not always ensure the transfer of compatible pollens.
- Hence, the pistil has the ability to recognise the right type of pollen to promote post- pollination events.
- If the pollen is of the wrong type, the pistil prevents pollen germination.
- This interaction is mediated by chemical components of the pollen and the pistil.

- Pollen–pistil interaction is a dynamic process involving pollen recognition, followed by promotion or inhibition of the pollen.
- The pollen tube reaches the ovary and enters the ovule through the micropyle. Then, through the filiform apparatus, it reaches synergids. In this way, the pollen tube grows.

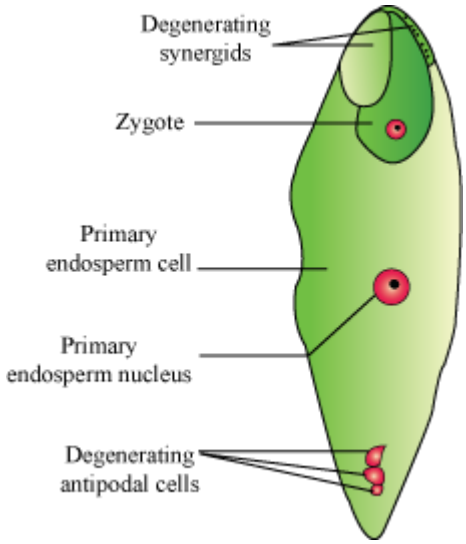
Artificial Hybridisation & Double Fertilisation

Artificial Hybridisation

- It is a method to improve crop yield.
- In this method, it is essential to ensure that the right kinds of pollen grains are used, and the stigma is protected from unwanted pollen grains. It is achieved by:
    - Emasculation – The anther is removed from the bud if the female parent bears bisexual flowers.
    - Bagging – The emasculated flower is covered by a bag so as not to allow contamination of the stigma by unwanted pollen grains.
- When the stigma of the bagged flower becomes receptive, the collected pollen grains are dusted onto the stigma, and then the flower is rebagged.
- If the female parent is unisexual, emasculation is not necessary. In this case, the female bud is directly bagged, and when the stigma turns receptive, suitable pollen grains are dusted onto it so as to allow germination.

Double Fertilisation

- When the pollen grains fall on the stigma, the pollen tube enters one of the synergids and releases two male gametes.
- One of the male gametes moves towards the egg cell and fuses with it to complete the **syngamy** to form the **zygote**.
- The other male gamete fuses with the two polar nuclei and forms triploid **primary endosperm nucleus (PEN)**. This is termed as **triple fusion**.
- Since two kinds of fusion—syngamy and triple fusion—take place, the process is known as double fertilisation, and is characteristic of flowering plants.
- After triple fusion, the central cell becomes the primary endosperm cell (PEC).
- The primary endosperm nucleus gives rise to the endosperm, while the zygote develops into the embryo.



Post-Fertilisation Events

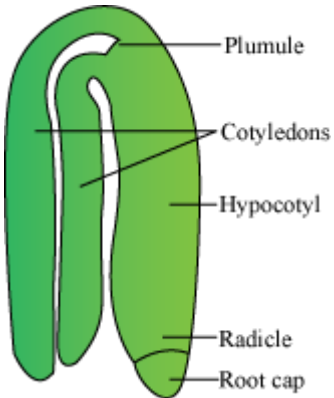
It includes development of endosperm and embryo, and maturation of ovules into seeds and ovaries into fruits.

Formation of Endosperm

- The endosperm develops before the embryo because the cells of the endosperm provide nutrition to thedeveloping embryo.
- The primary endosperm nucleus repeatedly divides to give rise to free nuclei. This stage of development is called free nuclear endosperm.
- Cell wall formation occurs next, resulting in a cellular endosperm.
- The endosperm may be either fully consumed by the growing embryo (as in pea and beans) or retained in the mature seed (as in coconut and castor).

Development of Embryo

- The embryo develops at the micropylar end of theembryo sac where the zygote is situated.
- The zygote gives rise first to the pro-embryo, and thento the globular, heart-shaped, mature embryo.
- A typical **dicot embryo** consists of an embryonal axisand two cotyledons.
- The portion of the embryonal axis above the level of cotyledons is called epicotyl. It contains the plumule (shoot tip). The portion below the axis is called hypocotyl. It contains the radicle (root tip). The root tip is covered bythe root cap.
- In a **monocot embryo**, there is only one cotyledon. In grass, it is known as the scutellum, and is situated at one side of the embryonal axis. At its lower end, theembryonal axis has the radicle and the root cap enclosed in the coleorrhiza.



- The epicotyl lies above the level of the scutellum, andhas the shoot apex and leaf primordia enclosed in hollow structures called coleoptiles.

Development of Seeds

- It is the last stage of sexual reproduction inangiosperms.
- Seeds are the fertilised ovules that are developed insidea fruit.
- A seed consists of:
    - Seed coat
    - Cotyledons
    - Embryonal axis
- Seeds may be **albuminous** (endosperm present; as in wheat and maize) or **non-albuminous** (endosperm absent; since it is consumed by the growing embryo; as in pea and beans).
- Some seeds such as black pepper and wheat haveremnants of nucellus known as **perisperm**.
- The integuments of ovules harden to form the seed coat, and the micropyle facilitates the entry of oxygen and water into the seed.
- As it loses moisture, the seed may enter dormancy, or if favourable conditions exist, it germinates.

Development of Fruits

- The ovary of a flower develops into a fruit.
- The walls of the ovary transform into the walls of thefruit (pericarp).
- Fruits may be fleshy, as in mango and orange, or canbe dry, as in groundnut and mustard.
- In some plants, floral parts other than the ovary take partin fruit formation, as in apple and strawberry. In these, the thalamus contributes to fruit formation. Such fruits are called **false fruits**. Fruits that develop from the ovary are called **true fruits**.
- Some fruits develop without fertilisation, and are known as **parthenocarpic fruits** (example: banana).

Apomixis and Polyembryony

- Some plants produce seeds without fertilisation. Thisprocess of seed formation is known as apomixis.
- Apomixis is a form of asexual reproduction mimicking sexual reproduction.
- In some species, apomixis occurs as the diploid egg cell is formed without meiosis, and develops into embryowithout fertilisation.
- In some varieties of citrus and mango, the nucellus cells divide and protrude into the embryo sac to developinto embryos. In such cases, each ovule may contain several embryos and this condition is called polyembryony.
- Apomixis is important for producing hybrid varieties offruits and vegetables, and also for increasing crop yield multifold.

Cheapter 6

MOLECULAR BASIS OF INHERITANCE

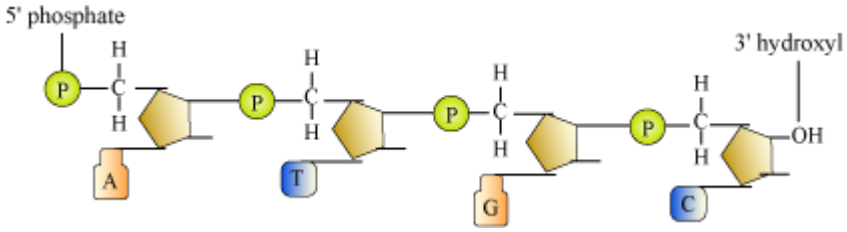
DNA : Structure of Polynucleotide Chain

- DNA − Polymer of deoxyribonucleotides
- Nucleoside = Nitrogenous base + Pentose sugar (linked through *N* − **glycosidic bond**)

  Example − adenosine, deoxyadenosine, cytidine, etc.
- Nucleotide = Nucleoside + Phosphate group (linked through **phosphodiester bond**)
- Many nucleotides link together through 3′ − 5′ **phosphodiester bond** to form polynucleotide chain (as in DNA and RNA).
- In course of formation of polynucleotide chain, a phosphate moiety remains free at 5′ end of ribose sugar (5′ end of polymer chain) and one -OH group remains free at 3′ end of ribose (3′ end of polymer chain).

Double Helix Model for the Structure of DNA

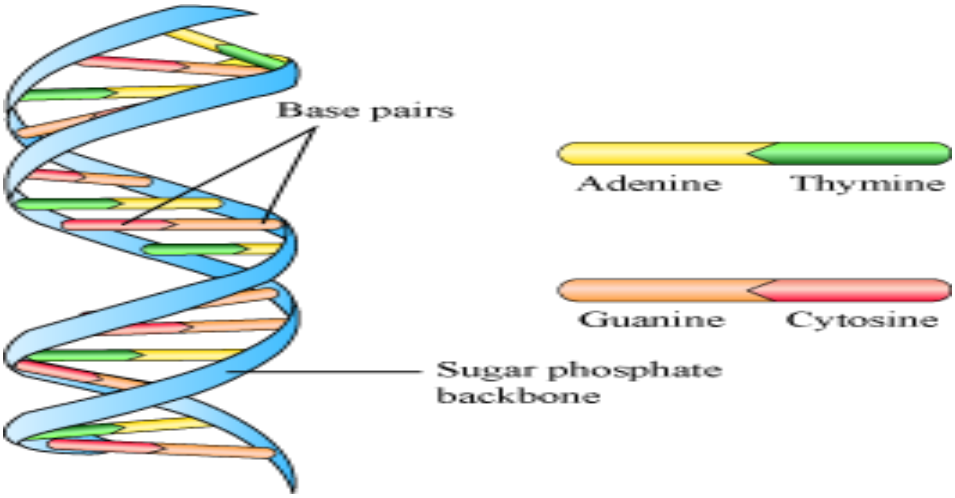
- Scientists involved

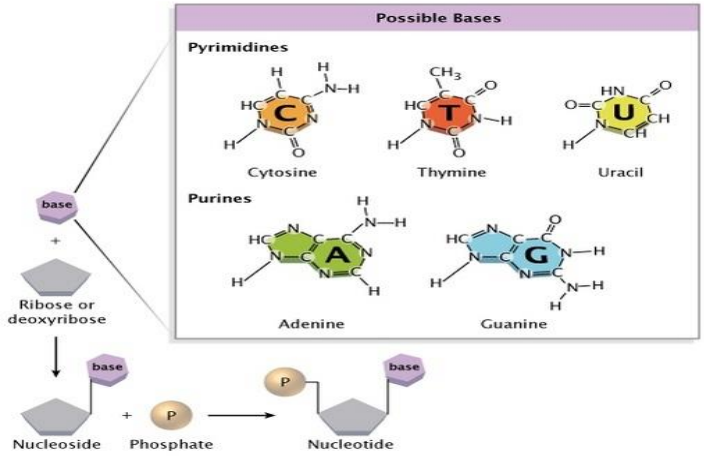


  - **Friedrich Meischer** − First identified DNA as an acidicsubstance present in nucleus and named it as ‘Nuclein’
  - **Wilkins and Franklin** − Produced X-ray diffraction data forDNA structure
  - **Watson and Crick** − Proposed double helix structure model forDNA based on X-ray diffraction data
  - **Erwin Chargaff** − Proposed that in ds DNA, ratios A:T and C:Gremain same and are equal to one

Features of double helix structure of DNA

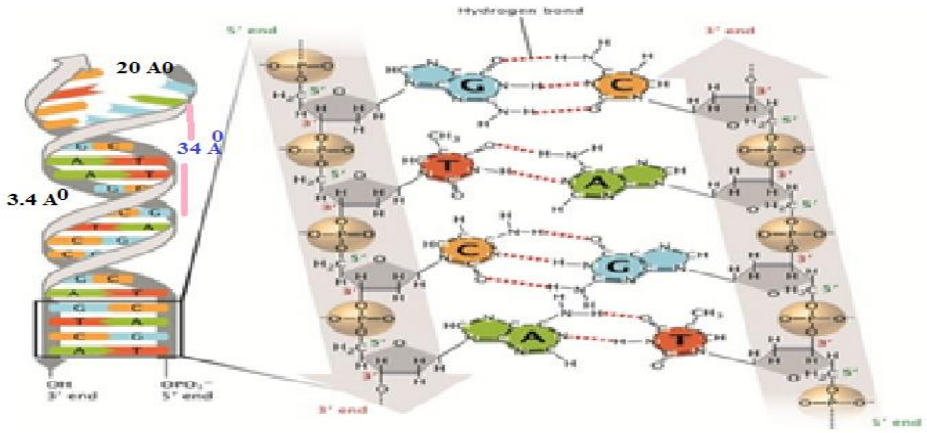
In a DNA, two polynucleotide chains are coiled to form a helix. Sugar- phosphate forms backbone of this helix while bases project in wards to each other.


Base pairs
Adenine
Thymine
Guanine
Cytosine
Sugar phosphate backbone


Possible Bases
Pyrimidines
Cytosine
Thymine
Uracil
Purines
Adenine
Guanine
base
Ribose or deoxyribose
Nucleoside
Phosphate
Nucleotide
P

- Complementary bases pair with each other through hydrogen bond. Purines always pair with their corresponding pyrimidines. Adenine pairs with thymine through two hydrogen bonds while guanine pairs with cytosine through three hydrogen bonds.

    - The plane of one base pair stacks over the other in a double helix. This provides stability to the helix along withhydrogen bonding.



DNA replication

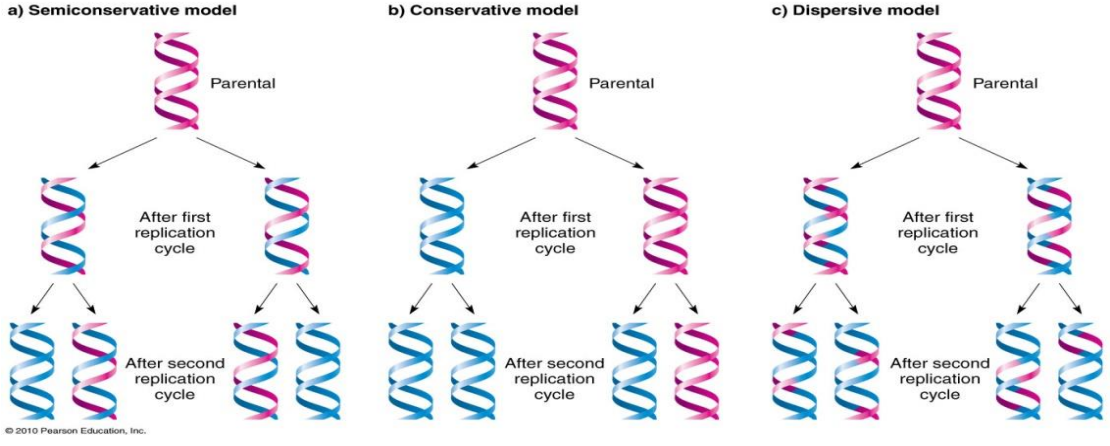
A. Semiconservative replication.
B. Conservative
C. Dispersive

In molecular biology, **DNA replication** is the biological process of producing two identical replicas of DNA from one original DNA molecule. DNA replication occurs in all living organisms acting as the most essential part for biological inheritance. The cell possesses the distinctive property of division, which makes replication of DNA essential. Three methods of DNA replication.

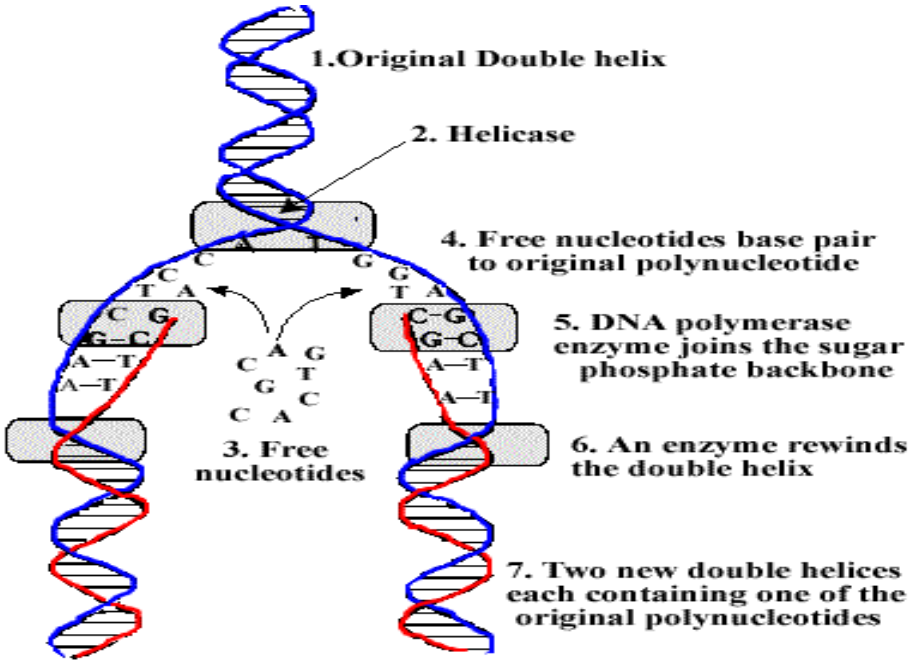
DNA is made up of a double helix of two complementary strands. During replication, these strands are separated. Each strand of the original DNA molecule then serves as a template for the production of its counterpart, a process referred to as semiconservative replication. As a result of semi-conservative replication, the new helix will be composed of an original DNA strand as well as a newly synthesized strand.

In a cell, DNA replication begins at specific locations, or origins of replication, in the genome.Unwinding of DNA at the origin and synthesis of new strands, accommodated by an enzyme known as helicase, results in replication forks growing bi-directionally from the origin. A number of proteins are associated with the replication fork to help in the initiation and continuation of DNA synthesis. Most prominently, DNA polymerase synthesizes the new strands by adding nucleotides that complement each (template) strand. DNA replication occurs during the S-stage of interphase.

DNA replication (DNA amplification) can also be performed *in vitro* (artificially, outside a cell). DNA polymerases isolated from cells and artificial DNA primers can be used to start DNA synthesis at known sequences in a template DNA molecule. Polymerase chain reaction (PCR), ligase chain reaction (LCR), and transcription-mediated amplification (TMA) are examples.



Mechanism of DNA replication

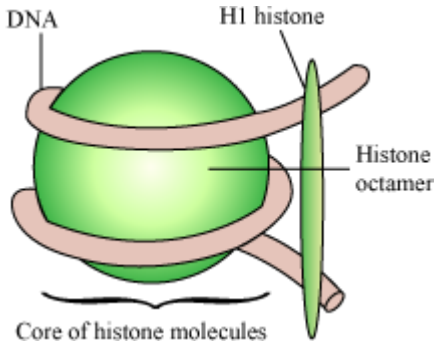


Packaging of DNA Helix

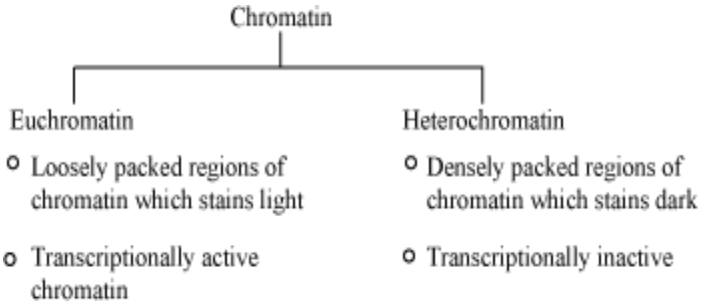
- Distance between two consecutive base pairs in a DNA = 0.34 nm = 0.34×10^{-9} m
- Total number of base pairs in a human DNA = 6.6×10^{9} bp
- Total length of human DNA = $0.34 \times 10^{-9} \times 6.6 \times 10^{9}$

  = ~ 2.2 m

- 2.2 m is too large to be accommodated in the nucleus (10^{-6} m).
- Organisation of DNA in prokaryotes:
  - They do not have nucleus. DNA is scattered.
  - In certain regions called nucleoids, DNA (negatively charged) is organised in large loops and is held by some proteins (positively charged).
- Organisation of DNA in eukaryotes:
  - They have positively charged basic proteins called histones (positive and basic due to presence of positive and basic amino acid residues, lysine and arginine).
  - Histone octamer − Unit of eight molecules of histone
  - DNA (negatively charged) winds around histone octamer (positively charged) to form nucleosome.



- Nucleosomes in a chromatin resemble beads present on strings.
- Beads on string structure in chromatin are further packaged to form chromatin fibres, which further coil and condense to form chromosomes during metaphase.
- Non-histone chromosomal proteins − Additional set of proteins required for packaging of chromatin at higher level



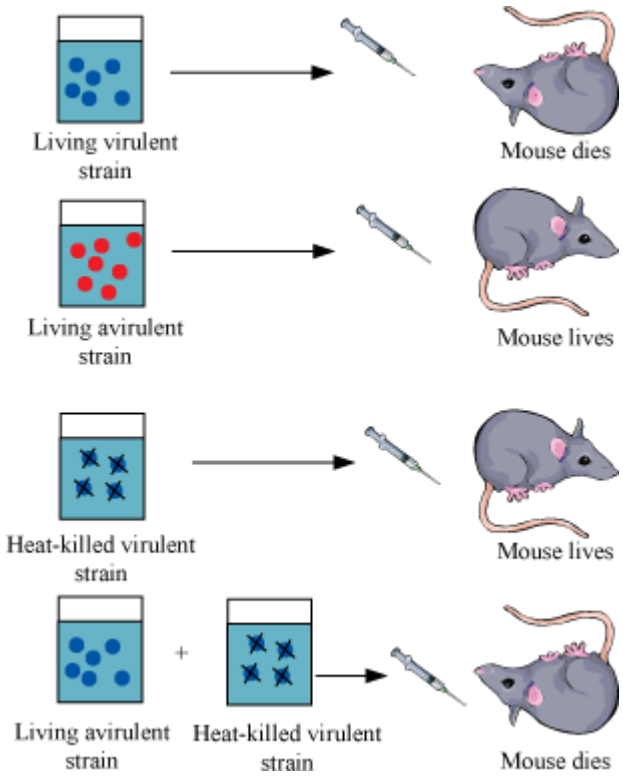
Transforming principle, Hershey and Chase experiments, & Properties of genetic material.

- Though principles of inheritance and discovery of chromosomes in nucleus were achieved long time back, there was confusion about which molecule acted as genetic material.Transforming Principle

- Griffith performed experiments with the bacteria *Streptococcus pneumoniae*. This bacterium has two strains − S strain and R strain.

S strain Bacteria	R strain Bacteria
Produce smooth colonies on culture plate	Produce rough colonies on culture plate
Have a polysaccharide coat	Do not have a polysaccharide coat
Virulent (causes pneumonia)	Non-virulent (does not cause pneumonia)

- Griffith’s experiment



- Live R strain in the presence of heat-killed S strain produce virulence because somehow R strain bacteria is transformed by heat-killed S strain bacteria. Hence, it was concluded that there must be transfer of genetic material.

Biochemical Nature of Transforming Material

- Avery, McLeod, and McCarthy worked to determine the biochemical nature of genetic material responsible for transformation.

$$\text{Heat-killed S strain} + \text{Live R strain} \xrightarrow[\text{Digest RNA and proteins}]{\text{RNase, Proteases}} \text{Transformation occurs and mouse dies}$$

$$\text{occur and mouse survives}$$

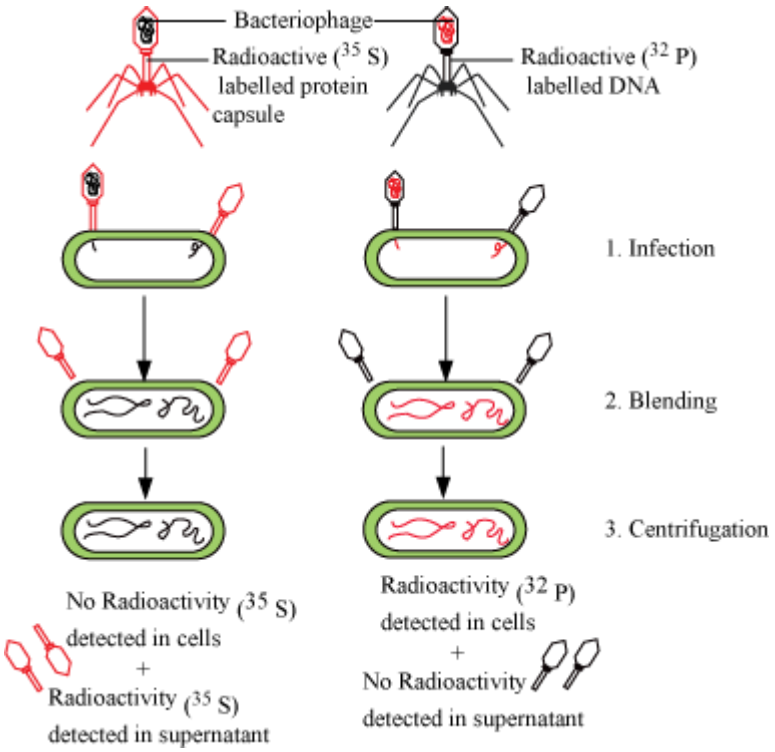
- This suggests that DNA has to be the genetic material.

Hershey and Chase Experiment to Confirm DNA as the Genetic Material

Hershey and Chase worked on bacteriophages (viruses that infect bacteria).

- When a bacteriophage infects a bacterium, the viral genetic material gets attached with the bacterial genetic material and bacteria then treats the viral genetic material as its own to synthesise more viral particles.
- Hershey and Chase worked to discover whether it was a protein or DNA that entered the bacteria from virus.
- They labelled some phages with radioactive sulphur and the others with radioactive phosphorus.
- These radioactive phages were used to infect *E. coli*.
- *E.coli* was then blended and centrifuged to remove viral particles.
- It was observed that bacteria with radioactive DNA were radioactive while those with radioactive proteins lost their radioactivity.
- This showed that it is the DNA that enters the bacteria from viruses and not proteins. Hence, it was concluded that DNA is the genetic material.

.



Properties of the Genetic Material

- It should be able to replicate (duplicate to produce its identical copy).
- It should be chemically and structurally stable.
- It should have scope for changes that are essential for evolution.
- It should follow the Mendelian principles of inheritance.
- Difference between DNA and RNA:

DNA	**RNA**
Has deoxyribose sugar	Has ribose sugar
5-methyl uracil (thymine) is present.	Uracil is present in place of thymine.
Mostly DNA acts as the genetic material.	RNA acts as a messenger and adaptor. It acts as a genetic material in some viruses.
DNA is stable.	Presence of 2′ OH group at every nucleotide makes RNA labile and easily biodegradable.
Chemically less reactive, mutates slowly	Mutation in RNA is faster.
DNA requires RNA for protein synthesis. DNA → RNA → Protein	RNA directly codes for proteins.

Why DNA is more stable than RNA?

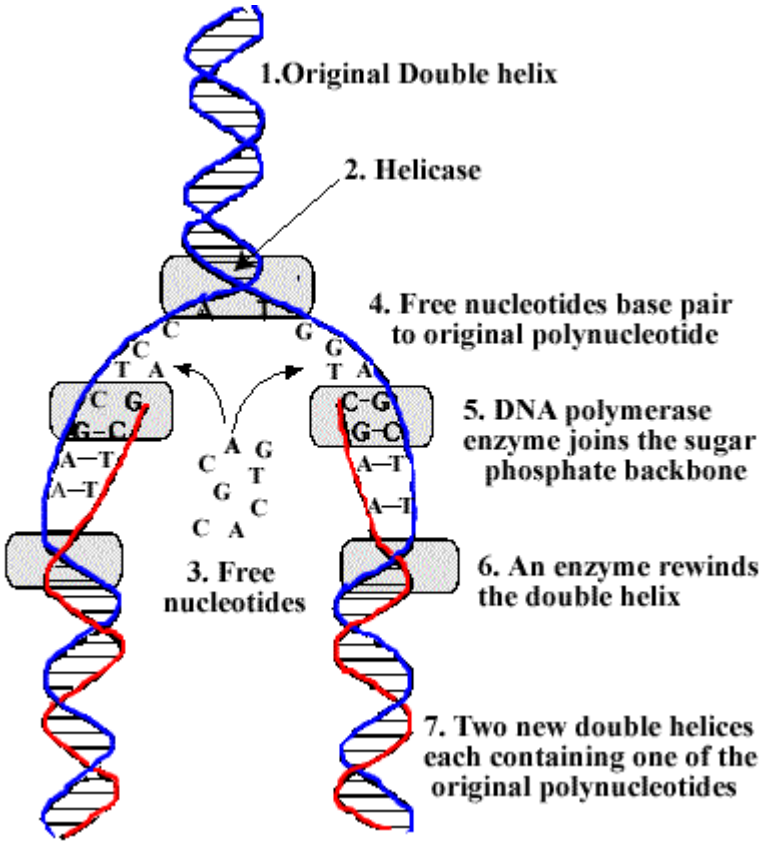
- In RNA, a 2′ OH group is present at every nucleotide. This makes RNA unstable and degradable.
- Presence of thymine in place of uracil confers additional stability to DNA.
- RNA being a biocatalyst is more reactive.
- DNA is double-stranded having complementary strand, which resists the changes by repair mechanism.

DNA Replication with Experimental Proof Machinery and Enzymes Involved

What is DNA Replication?

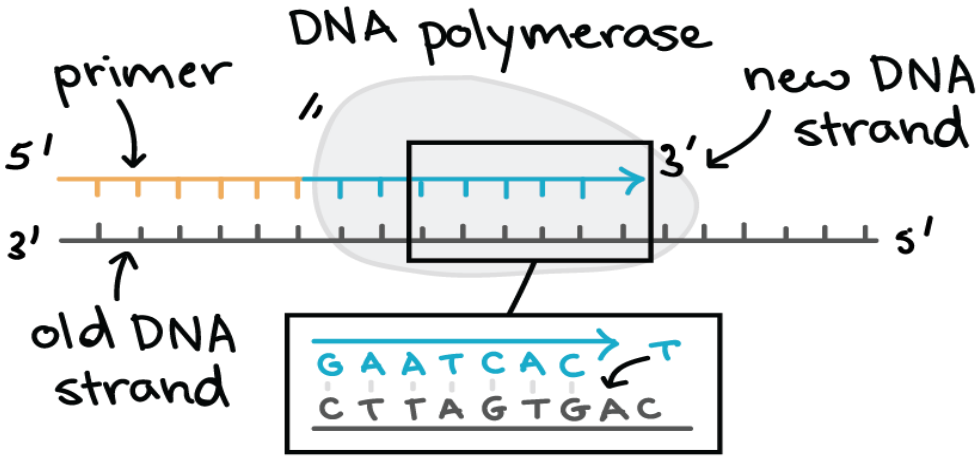
- DNA replication is the phenomenon in which a duplicate copy of DNA is synthesised.
- In replication, two strands of the DNA helix separate and each strand acts as a template for synthesising new complementary strands.

After completion of replication, the two copies so produced will have one parental and one newly synthesised strand. This scheme of replication is called semi-conservative replication.



Mechanism of DNA Replication

- DNA double helix.
- Hydrogen bonds break and helix opens.
- Each strand of DNA acts as a template for synthesis of a new, complementary strand.
- Replication produces two identical DNA double helices, each with one new and one old strand.
- In a sense, that's all there is to DNA replication! But what's actually most interesting about this process is how it's carried out in a cell.
- Cells need to copy their DNA very quickly, and with very few errors (or risk problems such as cancer). To do so, they use a variety of enzymes and proteins, which work together to make sure DNA replication is performed smoothly and accurately.
- DNA polymerases are responsible for synthesizing DNA: they add nucleotides one by one to the growing DNA chain, incorporating only those that are complementary to the template.



- They can only add nucleotides to the 3' end of a DNA strand
- They can't start making a DNA chain from scratch, but require a pre-existing chain or short stretch of nucleotides called a primer
- They proof read, removing the "wrong" nucleotides that are accidentally added to the chain.

The addition of nucleotides requires energy. This energy comes from the nucleotides themselves, which have three phosphates attached to them (much like the energy-carrying molecule ATP). When the bond between phosphates is broken, the energy released is used to form a bond between the incoming nucleotide and the growing chain.

DNA is a double-stranded molecule; one DNA strand is antiparallel to the other strand. Therefore, one strand runs in the 3’ to 5’ direction while the other runs in the 5’ to 3’ direction. The strand that runs in the 3’ to 5’ direction is known as the **leading strand** while the one that runs in the 5’ to 3’ direction is known as the **lagging strand**. The leading strand is so called because a continuous growth of the newly-synthesizing DNA strand can be observed on the leading strand. The DNA synthesis on the leading and lagging strands are shown in *figure 2*.

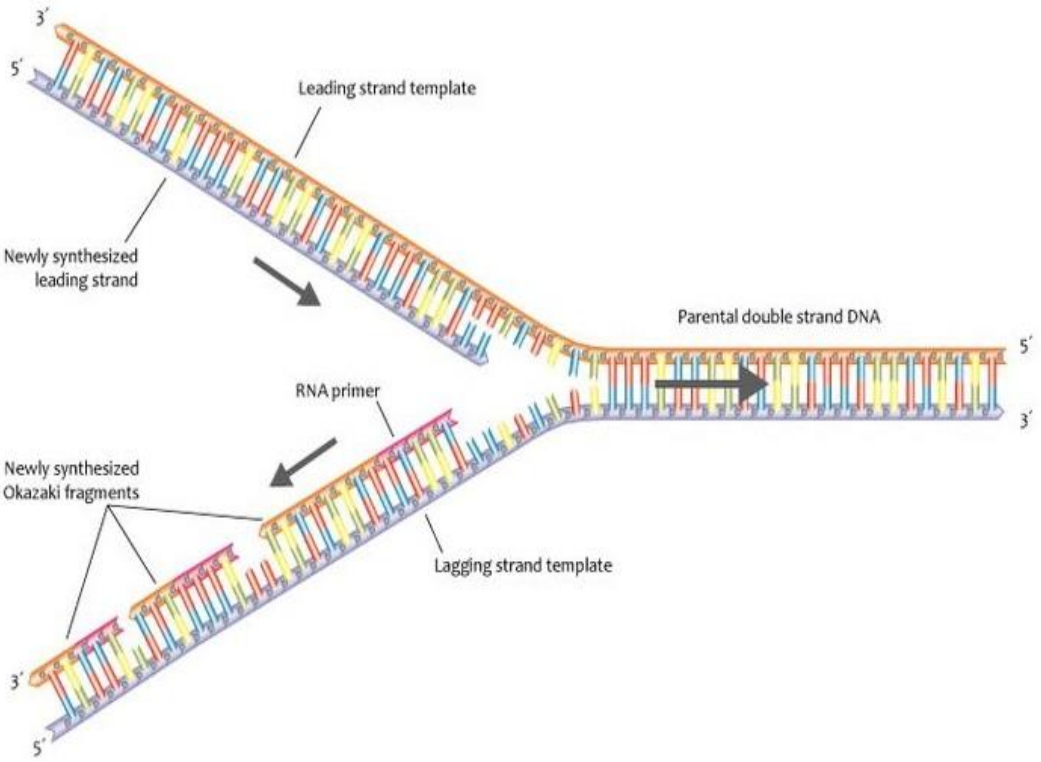


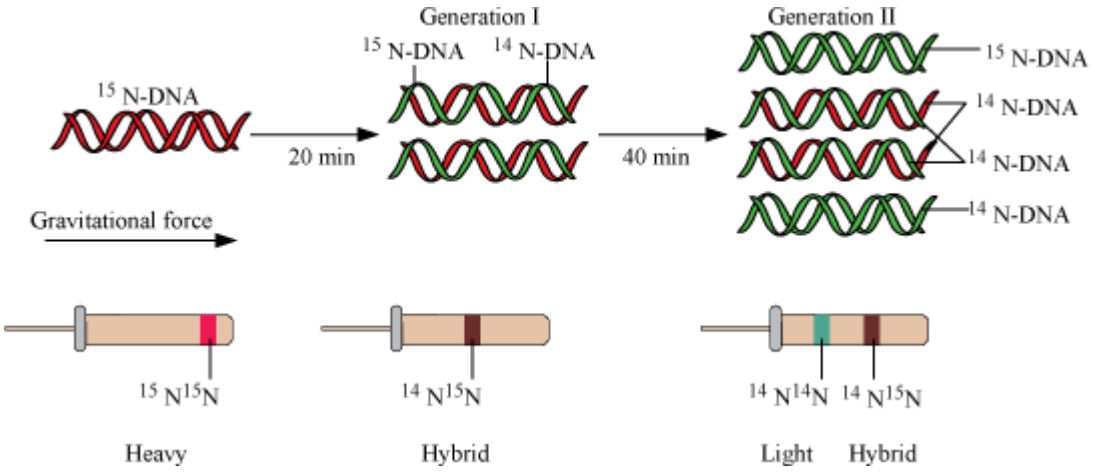
Figure 2: DNA Synthesis on Leading and Lagging Strands

Generally, DNA polymerase adds nucleotides in the 5' to 3' direction. Since the leading strand runs in the 3' to 5' direction, the enzyme can continuously add nucleotides to the growing strand on the leading strand. However, since the lagging strand runs in the 5' to 3' direction, the chain growth of the newly-synthesizing DNA strand is paused when it reaches the 5' end of the strand. Then the synthesis of another DNA strand begins at the replication fork. The replication fork is the position on the DNA double-strand where the unwinding begins. Unwinding is critical in the synthesis of new DNA strands on the original strands. Once the replication fork moves forward on the DNA double-strand, DNA polymerase can add nucleotides onto the lagging strand. However, the synthesis is paused when it reaches 5' end of the RNA primer of the already-synthesized DNA stretch. Hence, the DNA synthesis at the lagging strand is discontinuous and the resultant DNA stretches are known as Okazaki fragments.

Experiment to Prove That DNA Replicates Semi-Conservatively

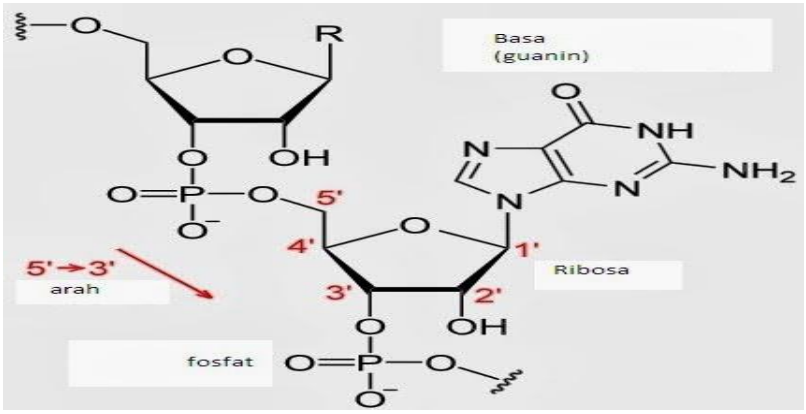
- Performed by − Messelson and Stahl
- *E.coli* was grown in a medium containing heavy isotope ^{15}N as the nitrogen source.
- ^{15}N was incorporated into newly synthesised DNA as well and the DNA became heavy DNA.
- Heavy DNA molecule can be differentiated from normal DNA by density gradient centrifugation using cesium chloride as the gradient.
- Then, cells were again transferred into a medium with ^{14}N as nitrogen source. Samples were taken from this media and their DNA was extracted.
- *E .coli* divides every 20 minutes. Therefore, the DNA extracted after 20 minutes had a hybrid density.
- DNA extracted after 40 minutes had equal amount of hybrid and light intensities.

- This implies that the newly synthesised DNA obtained one of its strands from the parent. Thus, replication is semi-conservative.



RNA

Consist of ribose nucleotide



Types of RNA & Transcription Proces

- mRNA (messenger RNA) − It serves as a template for protein synthesis. DNA is transcribed to form an mRNA, which in turn is translated to form protein. [Central dogma of molecular biology]
- tRNA (transfer RNA) − It brings amino acids during translation and reads the genetic code.
- rRNA (ribosomal RNA) − These are the work benches of translation. They playa structural and catalytic role during translation.

Transcription Unit --- Structure and its Relationship with a Gene.

Transcription

- Transcription is the process of formation of RNA molecules from the DNA.
- During transcription, only a segment of DNA from only one of the strands participates.
- Both strands are not copied during transcription because:
  - If both strands get transcribed at the same time since the sequences of amino acid would be different in both (due to complementarity), then two RNA molecules with different sequences will be formed, which in turn give rise to two different proteins. Therefore, one DNA would end up giving rise to two different proteins.
  - Two RNA molecules so formed will be complementary to each other, hence would end up forming a double-stranded RNA
- leaving the entire process of transcription futile.

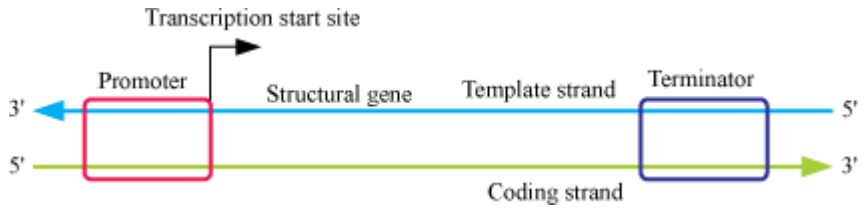
Transcriptional Unit

- A transcriptional unit has primarily three regions:
  - Promoter − Marks the beginning of transcription; RNA polymerase binds here
  - Structural gene − Part of the DNA that is actually transcribed
  - Terminator − Marks the end of transcription

Template Strand and Coding Strand

- Enzyme involved in transcription, RNA polymerase (DNA dependent RNA polymerase), catalyses in only one direction i.e., 5′ to 3′.
- Therefore, the strand with polarity 3′ → 5′ acts as a template (Template Strand).
- The strand with polarity 5′ → 3′ acts as coding strand (which is a misnomer since it does not code for anything). Coding strand has sequence similar to RNA formed after transcription except for the change that thymine is present instead of uracil.

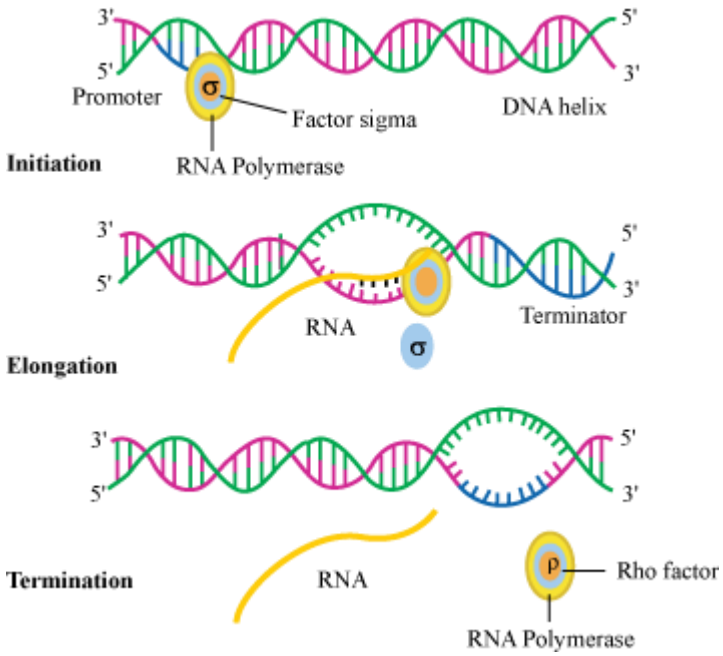
Gene



- The DNA sequence which codes for tRNA or rRNA molecule defines a gene.
- Cistron − Segment of DNA that contains the genetic code for a single polypeptide
  The structural genes could be of two types:
  Monocistronic (mostly in eukaryotes)
  Polycistronic (mostly in prokaryotes)
- Monocistronic genes have two parts:
  - Exon − Sequences that code for a particular character and is expressed in a matured and processed mRNA
  - Intron − Interrupting sequences that do not appear in a mature and processed mRNA
- Regulatory genes − Sequences that do not code for anything, but have regulatory functions

Transcription Process

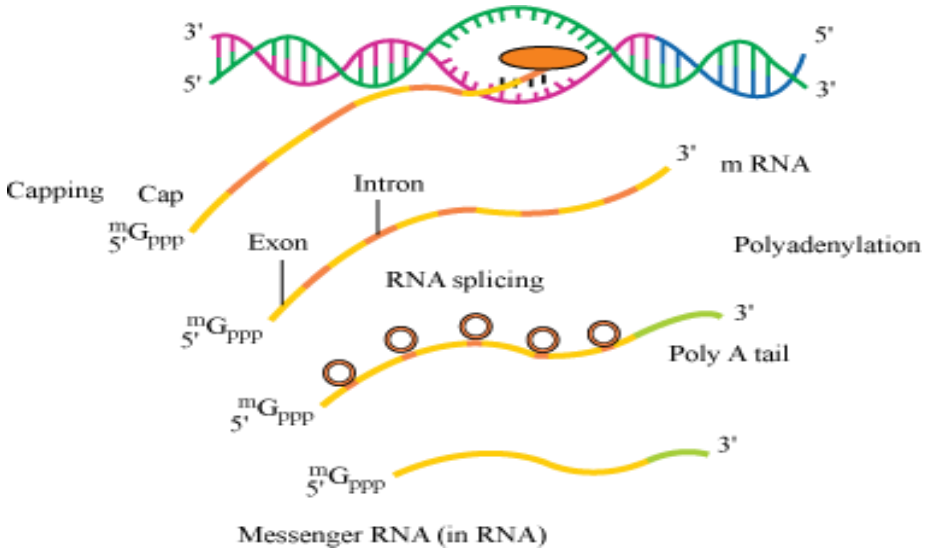
- Transcription has three steps − initiation, elongation, and termination.
- Initiation:
  - RNA polymerase binds with the promoter to initiate the process of transcription.
  - Association with initiation factor (σ) alters the specificity of RNA polymerase to initiate the transcription.
- Elongation**:**
  - RNA polymerase uses nucleotide triphosphate as substrate, and polymerisation occurs according to complementarity.
- Termination:
  - Termination occurs when termination factor (P) alters the specificity of RNA polymerase to terminate the transcription. As the RNA polymerase proceeds to perform elongation, a short stretch of RNA remains bound to the enzyme. As the enzyme reaches the termination region, this nascent RNA falls off and transcription is
  - terminated.



Complexities Associated with Transcription

- In prokaryotes:
  - There is no clear demarcation between cytosol and nucleus. Therefore, translation can begin even before transcription is completed. Thus, in prokaryotes, transcription and translation are coupled.

- In eukaryotes:
  - Three different kinds of RNA polymerases are present. RNA polymerase I transcribes rRNA.
  - RNA polymerase II transcribes hnRNA (mRNA precursor). RNA polymerase III transcribes tRNA, snRNA, and srRNA.
  - The precursor of mRNA, i.e. hnRNA, contains both introns and exons. Introns are removed and exons are joined by a process called splicing.
  - Capping − In this, methyl guanosine triphosphate is added to the 5′ end of hnRNA.
  - Tailing − In this, adenylate residues are added to the 3′ end of hnRNA.
  - When hnRNA is fully processed, it is known as mRNA, which is transported out of the nucleus to get translated.



Genetic Code and Study of Mutations

Genetic Code

- Genetic code directs the sequence of amino acids during the synthesis of proteins.
- George Gamow proposed that if 20 amino acids are to be coded by 4 bases, then the code should be made up of three nucleotides. $4^3 = 64$ ($4^2 = 16$), which is less than 20; so, the codon was proposed to be triplet.
- Har Gobind Khorana developed a chemical method to synthesise RNA molecules with defined combination of bases.
- Nirenberg developed cell-free systems for protein synthesis, which helped the code to be deciphered.
- The enzyme known as Severo Ochoa enzyme (polynucleotide phosphorylase) helped to polymerise RNA with defined sequences in a template independent manner.
- It finally gave rise to the checker-board for genetic code.

The Codons for the Various Amino Acids

First position	Second position U	Second position C	Second position A	Second position G	Third position
U	UUU Phe	UUU Ser	UUU Tyr	UUU Cys	U
	UUC Phe	UUC Ser	UUC Tyr	UUC Cys	C
	UUA Leu	UUA Ser	UUA Stop	UUA Stop	A
	UUG Leu	UUG Ser	UUG Stop	UUG Trp	G
C	CUU Leu	CUU Pro	CUU His	CUU Arg	U
	CUC Leu	CUC Pro	CUC His	CUC Arg	C
	CUA Leu	CUA Pro	CUA Gin	CUA Arg	A
	CUG Leu	CUG Pro	CUG Gin	CUG Arg	G
A	AUU Ile	AUU Thr	AUU Asn	AUU Ser	U
	AUC Ile	AUC Thr	AUC Asn	AUC Ser	C
	AUA Ile	AUA Thr	AUA Lys	AUA Arg	A
	AUG Met	AUG Thr	AUG Lys	AUG Arg	G
G	GUU Val	GUU Ala	GUU Asp	GUU Gly	U
	GUC Val	GUC Ala	GUC Asp	GUC Gly	C
	GUA Val	GUA Ala	GUA Glu	GUA Gly	A
	GUG Val	GUG Ala	GUG Glu	GUG Gly	G

- Salient features of genetic code:
  - Codon is triplet. $4^3 = 64$ (61 codons code for amino acids while 3 are stop codons)
  - One codon codes for a single specific amino acid. Codons are unambiguous.
  - Codons are degenerate since some amino acids are coded by more than one codon.
  - Genetic code is universal. 1 codon codes for same amino acid in all species.
  - Codons are read continuous. They lack punctuations.
  - AUG has dual functions − Codes for Methionine and acts as a start codon

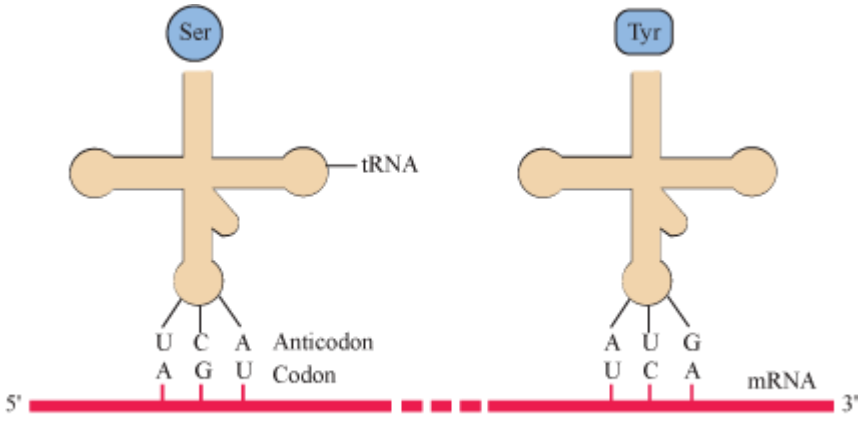
Effects of Mutations on Genetic Code

- Mutations include insertions, deletions, and rearrangements.
- Mutation results in changed phenotype and diseases such as sickle cell anaemia. (Change Glu → Val in gene coding for beta globin chain of haemoglobin) Such mutations are called **joint mutations**.
- Insertion or deletion of a single base pair disturbs the entire reading frame in mRNA. Such mutations are called **frameshift mutations**.
- Frameshift mutations hold the proof of the fact that codon is triplet because if we insert three or multiple of three bases followed by the deletion of same number of bases, then the reading frame will remain unaltered.

tRNA

- tRNA is an adapter molecule. On one hand, it reads the genetic code and on the other hand, it binds to specific amino acids.
- tRNA has an **anticodon loop** that has bases complementary to the mRNA code and an **amino acid acceptor end** where it binds to the corresponding amino acid.
- Initiation tRNA − This tRNA is essential for initiation of translation and has AUG in anticodon loop and Met in amino acid acceptor end.
- There are no tRNAs for stop codons.

.



Structure of tRNA molecule

Translation

- The mRNA contains the genetic information, which is translatedinto the amino acid sequence with help of tRNA. Amino acids are polymerised to form a polypeptide.
- Amino acids are joined by peptide bond.
- First of all, charging of tRNA (amino-acylation of tRNA) takes place. In this, amino acids are activated in the presence of ATP and are linked to their corresponding tRNA.
- Ribosomes are the workbenches for translation. Ribosomes have 2 subunits: a large subunit and a small subunit.
- Smaller subunit comes in contact with mRNA to initiate the process of translation.
- Translational unit in an mRNA is the region flanked by start codon and stop codon.
- Untranslated regions (UTR) are the regions on mRNA that are not themselves translated, but are required for efficient translation process. They may be present before start codon (5′ UTR) or after stop codon (3′ UTR).
- Initiator tRNA recognises the start codon. (Initiation)
- Then t-RNA-amino acid complexes bind to their corresponding codon on the mRNA and base pairing occurs between codon on mRNA and tRNA anticodon.
- tRNA moves from codon to codon on the mRNA and amino acids are added one by one. (Elongation)
- Release factor binds to stop codon to terminate the translation. (Termination)

Regulation of Gene Expression

- Regulation of gene expression could be exerted at following levels.
  - Transcriptional level (following of primary transcripts)
  - Processing level (splicing)
  - Transport of mRNA from nucleus to cytoplasm
  - Translational level
- In addition, metabolic, physiological, or environmental conditions regulate the expression of genes.
- Expression of genes coding for enzymes is required onlywhen substrate for that enzyme is available.

  For example:

  Lactose $\xrightarrow{\text{beta-galactosidase}}$ Glucose + Galactose

  E.coli synthesises beta-galactosidase, only when lactose is available.

- **Regulation in prokaryotes**
  - Gene expression is regulated by controlling the rate of transcriptional initiation.
  - The activity of RNA polymerase at a given promoter is regulated by accessory proteins. The accessory proteins affect the ability of a promoter to recognise start sites.
  - A regulatory protein could be activator or repressor.
  - Accessibility of promoter is also affected by operators. Operator is the region located adjacent to promoter.
  - Each operon has a specific operator and a specific repressor.
  - Usually operator binds to a repressor protein.

Regulation of Lac Operon

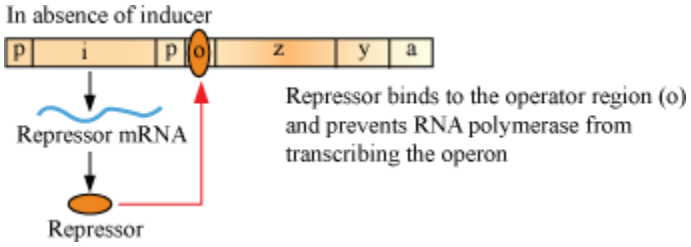
***Lac* Operon**

- Operon − An arrangement where a polycistronic gene is regulated by a common promoter and regulatory genes
- *Lac* operon, *trp* operon, *his* operon, *val* operon are the examples of such systems.
- The elucidation of *lac* operon as a transcriptionally active system was first done by geneticist Jacob and biochemist Monod.
- All genes involved in *lac* operon are required for metabolism of lactose.
- **Inducer** − Lactose acts as an inducer for *lac* operon since it regulates the switching on and off of the operon.
- If lactose is provided to the growth media of bacteria in absence of any other carbon source, then it is transported inside the cells by permease.
- For permease to be present and lactose to enter inside the cells, low level of expression of *lac* operon must be present all the time.

Regulation in Absence of Inducer

- In absence of inducer, *i* gene transcribes to synthesise repressor mRNA, which translates to form repressor.
- This repressor binds with the operator region of operon and prevents RNA polymerase to transcribe genes − *z*, *y*, and *a* (negative regulation).
- Therefore, in absence of the products of these genes, metabolism of lactose ceases.

Regulation in Presence of Inducer



- Inducer binds with the protein product of gene *i* (repressor) and inactivates it.
- This inactivated repressor is unable to inactivate RNA polymerase enzyme and *z*, *y*, and *a* genes synthesise their respective mRNA, which in turn gets translated to form β-galactosidase, permease, and all genes involved in *lac* operon are required for metabolism of lactose.
- In presence of all these enzymes, the metabolism of lactose proceeds in a normal manner.

Methods to Identify Genes

- Two methods − identifying ESTs (Expressed sequence Tags) and sequence annotation
- ESTs − As the name suggests, this refers to the part of DNA that is expressed,

  i.e. transcribed, as mRNA and translated into proteins thereafter. It basically focuses on sequencing the part denoting a gene.
- Annotation − In this approach, entire genome (coding + non-coding) is sequenced and later on function is assigned to each region in the genome.

Genome Sequencing

- DNA from the cells is isolated and is randomly broken into fragments of smaller sizes.
- These fragments are cloned into suitable host using vectors.
- Cloned fragments amplify in the host. Amplification facilitates an easy sequencing.
- Common vectors used − BAC (Bacterial artificial chromosomes) and YAC (Yeast artificial chromosomes)
- Common hosts − Bacteria and yeasts
- Automated sequencers are used to sequence these smaller fragments (Sanger sequencing).
- The sequences so obtained are arranged based on overlapping regions within them (alignment).
- Alignment of the sequences is also done automatically by computer programs.
- Then these sequences are annotated and assigned to each chromosome.

Preparation of Genetic and physical maps on Genome

- 2 methods are used − restriction polymorphism and microsatellites
- Restriction polymorphism − Specialized enzymes called restriction endonucleases are used to cut the genome at specialized sites called restriction endonuclease recognition site and maps are prepared based on it.
- Microsatellites − These are repetitive DNA sequences.

DNA Fingerprinting
Introduction

- DNA fingerprinting is a method for comparing the DNA sequences of any two individuals.
- 99.9% of the base sequences in all human beings are identical. It is the remaining 0.1% that makes every individual unique.
- It is a really difficult and time-consuming task to sequence and compare all 3×10^9 bases in two individuals. So, instead of considering the entire genome, certain specific regions called repetitive DNA sequences are used for comparative study.

Basis of DNA Fingerprinting

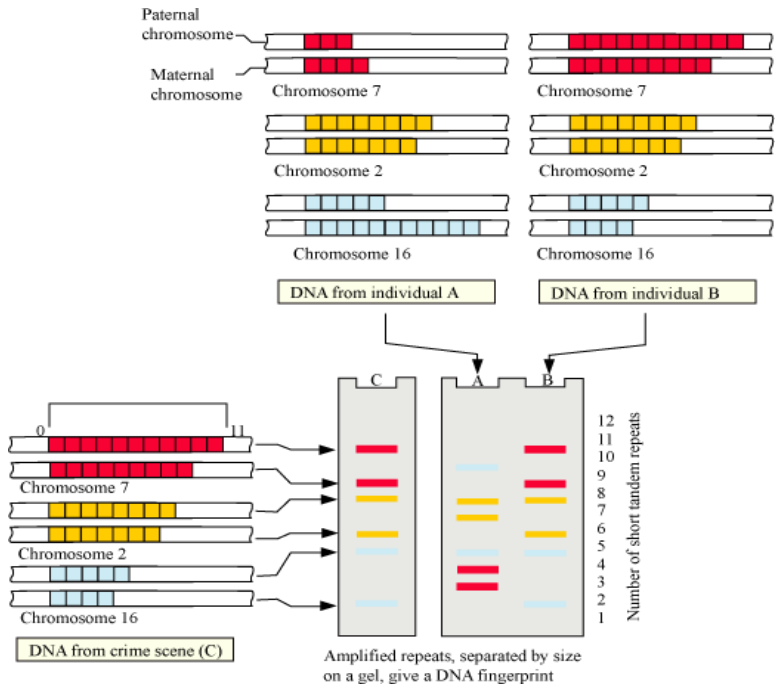
- Repetitive DNA is separated from bulk genomic DNA since it appears as a distinct peak during density gradient centrifugation.
- Major peak: Formed by bulk DNA Smaller peak:
  Satellite DNA.
- Satellites are of two types—micro-satellites and mini satellites, depending upon the base composition, length of segment and the number of repetitive units.
- Satellites do not code for proteins, but have a major role to play in DNA fingerprinting.
- Polymorphism is actually a result of mutation. A germ cell mutation (which can pass on to the next generation through sexual reproduction) gives rise to polymorphism in populations.
- In other words, an inheritable mutation if observed in higher frequencies in a population is known as polymorphism.
- Polymorphisms arise normally in non-coding sequences because mutations in non-coding sequences do not affect an individual's reproductive ability.

Methodology of DNA fingerprinting

- VNTR (variable number of tandem repeats) are satellite DNAs that show high degree of polymorphism.
- VNTRs are used as probes in DNA fingerprinting.
- First of all, DNA from an individual is isolated and cut withrestriction endonucleases.
- Fragments are separated according to their size and molecular weight on gel electrophoresis.
- Fragments separated on electrophoresis gel are blotted (immobilised) on a synthetic membrane such as nylon or nitrocellulose.
- Immobilised fragments are hybridised with a VNTR probe.
- Hybridised DNA fragments can be detected by autoradiography.
- VNTRs vary in size from 0.1 to 20 kb.
- Hence, in the autoradiogram, band of different sizes will be obtained.
- These bands are characteristic for an individual. They are different in each individual, except identical twins.

Applications of DNA Fingerprinting

- DNA fingerprinting is widely used in forensics since every DNA ofevery tissue from an individual has the same degree of polymorphism.
- DNA fingerprinting forms the basis of paternity testing since a child inherits polymorphism from both its parents.
- It can be used for studying genetic diversity in a population and evolution.

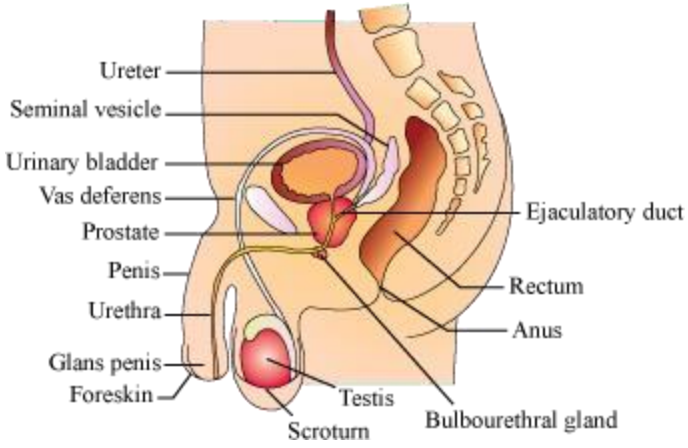


Reproduction in human

Male and Female Reproductive Systems

- Human beings reproduce sexually and are viviparous.
- In humans, the reproductive phase starts after puberty.
- It involves:
    - Gametogenesis
    - Insemination
    - Fertilisation
    - Implantation
    - Gestation
    - Parturition

- **The Male Reproductive System ;**



- It is located in the pelvic region.
- It consists of:
    - A pair of testes
    - Accessory glands and ducts
    - External genitalia

Testes

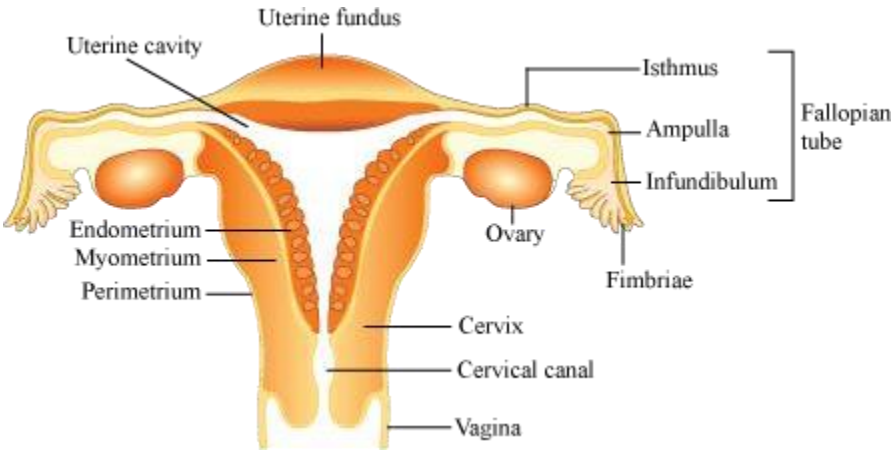
- Situated within the **scrotum**, which protects the testesand also helps in maintaining the temperature.
- Each testis is 4 to 5 cm in length, and 2 to 3 cm in width, and has about 250 compartments called **testicular lobules**.
- Testicular lobules have **seminiferous tubules** which arethe sites of sperm formation.
- Seminiferous tubules are lined by two types of cells:
    - **Male germ cells** − They undergo meiosis to formsperms.
    - **Sertoli cells** − They provide nourishment to the germcells.
- Region outside the seminiferous tubules is called the interstitial space, which contains **Leydig cells** (interstitial cells). The Leydig cells produce androgens.

Accessory Ducts and Glands

- Accessory ducts include:
    - Rete testis
    - Vasa efferentia
    - Epididymis
    - Vas deferens
- The seminiferous tubules open into the vasaefferentia through the **rete testis**.
- The vasa efferentia open into the **epididymis**, which leads to the **vas deferens**. The vas deferens opens into the urethra along with a duct from the seminal vesicle calledthe **ejaculatory duct**.
- The ejaculatory duct stores the sperms and transportsthem to the outside. The urethra starts from the urinary bladder, extendsthrough the penis and opens via the **urethral meatus**.
- Accessory glands include:
    - A pair of seminal vesicles
    - Prostate gland
    - A pair of bulbourethral glands

The secretions of these glands make up the seminalplasma, and provide nutrition and a medium of motility to the sperms.

- **The Female Reproductive System;**



- It is located in the pelvic region:
- It includes:
    - A pair of ovaries
    - A pair of oviducts
    - Uterus
    - Cervix
    - Vagina
    - External genitalia
    - Mammary glands (not part of the reproductive system, but aids in child care)

Ovaries

- They are the primary female sex organs. They produce the ovum and other ovarian hormones.
- They are located in the lower abdomen, and are 2 to 4 cm in length.
- They are connected by ligaments to the pelvic walls and to the uterus.
- Each ovary is covered by epithelium, and contains the ovarian stroma.
- The ovarian stroma is made up of:
    - Peripheral cortex
    - Inner medulla

Oviducts

- They are also called **fallopian tubes**.
- They are 10 to 12 cm long, and extend from the ovary to the uterus.
- The part of each oviduct lying towards the ovary is funnel shaped, and is called **infundibulum**. It has finger-like projections called **fimbriae**.
- The infundibulum leads to the ampulla, and then to the isthmus, which has a narrow lumen opening into the uterus.

Uterus

- It is also called **womb**, and is **pear shaped**.
- It is connected to the pelvic walls by ligaments.
- The uterine wall consists of:
  - External perimetrium
  - Middle myometrium
  - Internal endometrium, which lines the uterine cavity.
- The endometrium undergoes changes during the menstrual cycle.

Cervix and Vagina

- The cervix connects the uterus to the vagina.
- The cervix and the vagina constitute the birth canal.

External Genitalia

- Consists of:
  - Mons pubis − Fatty tissue covered by skin and pubic hair
  - Labia majora − Extends from mons pubis and surrounds the vaginal opening
  - Labia minora − Fold of skin beneath the labia majora
  - Hymen − Partially covers the vaginal opening
  - Clitoris − Lies at the junction of labia minora

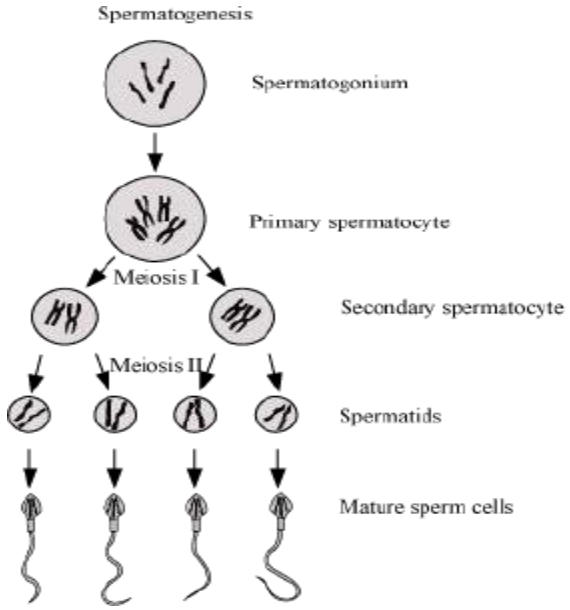
Mammary Glands

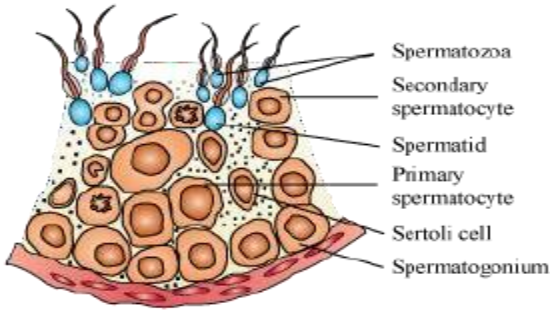
- Present in all female mammals
- It is **paired** and is **glandular**.
- Each breast contains 15 to 20 mammary lobes with **alveoli** which secrete milk.
- The alveoli open into the mammary tubules, which uniteto form a mammary duct.
- Many mammary ducts constitute the mammaryampulla, which is connected to the **lactiferous duct**.

Gametogenesis

The testis and ovary produce the male and female gametes respectively by gametogenesis (spermatogenesis in males and oogenesis in females).

Spermatogenesis





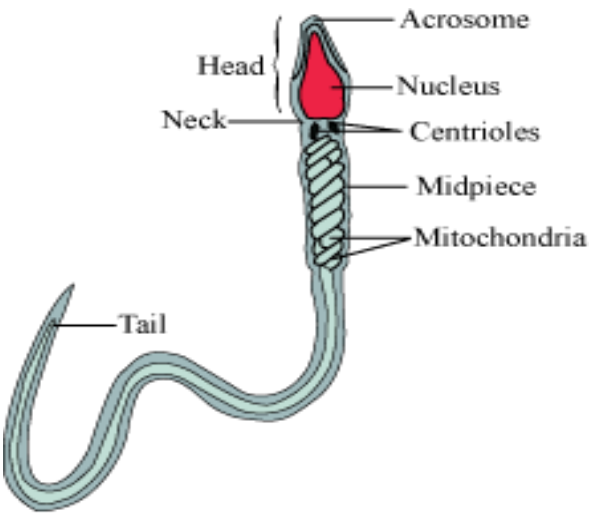
- In males, sperms are produced by the **spermatogonia** (immature germ cells), which are present in the inner walls of the seminiferous tubules

- Spermatogonia increase in number by mitosis. These are diploid.
  - Some of the spermatogonia called **primary spermatocytes** periodically undergo meiosis.
  - After the first meiotic division, two haploid and equal **secondary spermatocytes** are formed.
  - These further undergo meiosis to give rise to four haploid

Spermatids.

- These spermatids are converted into sperms by **spermiogenesis.**
- The sperm head gets embedded in the Sertoli cells after spermiogenesis and is released from the seminiferous tubules by **spermiation.**
- Spermatogenesis starts at puberty by the action of the gonadotropin releasing hormone (GnRH), which in turn causes the release of two gonadotropins called Luteinizing Hormone (LH) and Follicle Stimulating Hormone (FSH).
- LH acts on Leydig cells and causes them to release androgens, which stimulate the process of spermatogenesis while the FSH acts on the Sertoli cells, which help in spermiogenesis.

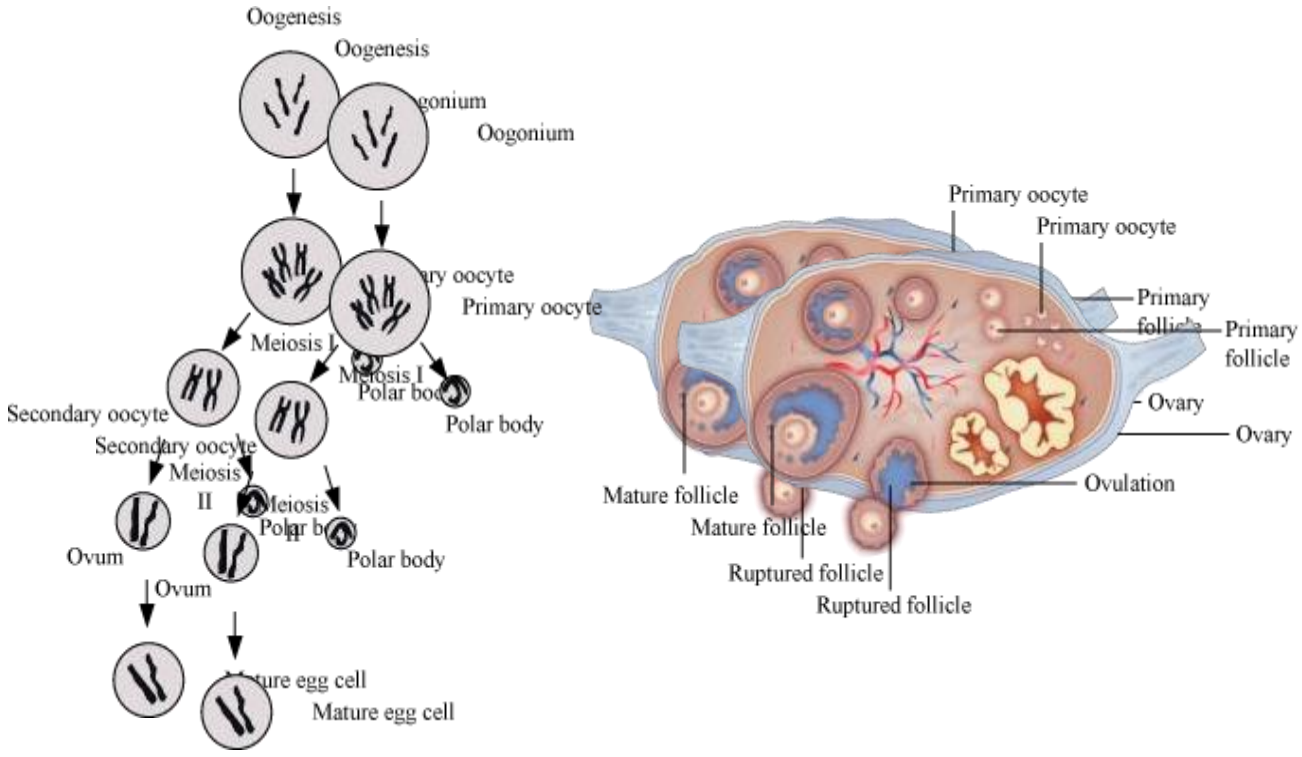
Structure of a Sperm



Sperm cell

- A mature sperm consists of:
    - Head
    - Neck
    - Middle piece
    - Tail
- The whole sperm is enclosed in a plasma membrane.
- The head consists of a haploid nucleus and a cap-like **acrosome**, which contains enzymes that aid in fertilisation.
- The middle piece contains several mitochondria, which produce energy for the motility of the sperm.
- Sperms released by the seminiferous tubules are transported by the accessory ducts.
- Secretions of epididymis, vas deferens, seminal vesicles, and prostate are essential for maturation and motility of sperms.

Oogenesis



- The ovum is formed by the process of oogenesis.
- It starts during embryonic growth and millions ofgamete mother cells (**oogonia**) are formed in the foetal ovary.
- These cells undergo meiosis, but get temporarily arrested at the prophase and are called **primary oocytes**.
- Before reaching puberty, a large number of primaryoocytes degenerate and the remaining ones get surrounded by layers of granulosa cells and new theca and are called **secondary follicles**.
- The secondary follicles are then converted into **tertiary follicles** that have characteristic fluid-filled cavity called antrum. At this stage, the primary oocyte present within the tertiary follicle completes meiosis, which results in the formation of haploid secondary oocyte and a tiny polarbody.
- This tertiary follicle further changes into the **Graafian follicle**. The secondary oocyte is surrounded by thezone pellucida.
- Then the Graafian follicle ruptures to release the ovum by **ovulation.**

Menstrual Cycle & Fertilisation

- Menstrual cycle is the reproductive cycle in all primates and begins at puberty (menarche).
- In human females, menstruation occurs once in 28 to 29 days. The cycle of events starting from one menstruationtill the next one is called the **menstrual cycle**.
- During the middle of the menstrual cycle, one ovumis released (ovulation).

  The cycle starts with the **menstrual flow** (3 to 5 days), caused due to the breakdown of the endometrium of the uterus. Blood vessels in liquid state are discharged, butthis occurs only when the ovum is not fertilised. It is followed by the **follicular phase**.In this phase, the primary follicles mature into the Graffian follicles. This causes the regeneration of the endometrium

  - These changes are brought about by ovarian and pituitary hormones. In this phase, the release of gonadotropins (LH and FSH) increases. This causes follicular growth and the growing follicles produce oestrogen.
  - The LH and FSH are at their peak in the middle of thecycle (14^{th} day), and cause the rupture of the Graffian follicles to release ovum. This phase is called the **ovulatory phase**.

- The remains of the Graffian follicles get converted intothe corpus luteum, which secretes progesterone for the maintenance of the endometrium.
- In the absence of fertilisation, the corpus luteum degenerates, thereby causing the disintegration ofthe endometrium and the start of a new cycle.
- In humans, the menstrual cycle ceases to operate at theage of 50 years. This phase is known as the **menopause**.

Fertilisation and Implantation

- During coitus, the semen is released into the vagina, passes through the cervix of the uterus and reaches the ampullary- isthmic junction of the fallopian tube.
- The ovum is also released into the junction for fertilisationto occur.
- The process of fusion of the sperm and the ovum isknown as fertilisation.
- During fertilisation, the sperm induces changes in the **zona pellucida** and blocks the entry of other sperms. This ensures that only one sperm fertilises an ovum.

  The enzymatic secretions of the acrosomes help the sperm enter the cytoplasm of the ovum.
- This causes the completion of meiotic division of the secondary oocyte, resulting in the formation of ahaploid ovum (ootid) and a secondary polar body.
- Then, the haploid sperm nucleus fuses with thehaploid nucleus of the ovum to form a diploid **zygote**.
- Mitosis starts as the zygote moves through the isthmus of the oviduct (cleavage) and forms 2, 4, 8, 16 daughtercells called **blastomeres**.
- The 8−16 cell embryo is called a **morula**, which continues to divide to form the **blastocyst**. The morula movesfurther into the uterus.
- The cells in the blastocyst are arranged into an outer **trophoblast** and an **inner cell mass**.
- The trophoblast gets attached to the uterineendometrium, and the process is called implantation. This leads to pregnancy.
- The inner cell mass gets differentiated to form theembryo.

Pregnancy, Parturition and Lactation

Pregnancy

- After implantation, the trophoblast forms finger-like projections called chorionic villi, surrounded by theuterine tissue and maternal blood.

- The chorionic villi and the uterine tissue get integrated to form the **placenta**, which helps in supplying the developing embryo with oxygen and nutrients, and is also involved in the removal of wastes.
- The placenta is connected to the embryo by the **umbilical cord**. The placenta acts as an endocrine gland, and produces the human chorionic gonadotropins, human placental lactogen, oestrogen, progesterone and relaxin (later stages of pregnancy).
- These hormones support foetal growth and help in the maintenance of pregnancy. Hormones like oestrogen, progestogen, cortisol, prolactin, etc., are increased several folds in the maternal blood.
- Immediately after implantation, the inner cell mass (embryo) gets differentiated into the ectoderm, mesoderm and endoderm, which give rise to the different tissues. This ability of the inner cell mass is due to the presence of multi- potent cells called **stem cells**.
- Most of the major organs are formed at the end of 12 weeks of pregnancy; during the 5^{th} month, the limbs and body hair are formed; by the 24^{th} week, the eyelids separate and eyelashes are formed. At the end of nine months, the foetus is fully formed.

Parturition and Lactation

- Human pregnancy has the duration of 9 months. This duration is called the **gestation period**.
- At the end of this period, vigorous uterine contractions lead to the delivery of the foetus. This process is called **parturition**.
- Parturition is a neuro-endocrine mechanism, and is started by the signals from the developed foetus and the placenta, which produce the **foetal ejection reflex**.
- This causes the release of oxytocin from the pituitary, which causes stronger uterine contractions.
- This leads to the expulsion of the baby along with the placenta.
- During pregnancy, the mammary glands undergo differentiation, and milk is produced during the end of pregnancy.
- The milk produced during the first few days of lactation is known as **colostrums**. It contains several antibodies that aid the newborn to develop resistance.