Plant Kingdom

3 Chapter

1 INTRODUCTION

- Our understanding of the plant kingdom has changed overtime.
- Fungi and members of the Monera and Protista having cell walls have now been excluded from plantae. Cyanobacteria that are also referred to as blue green algae are not algae anymore.
- In plant kingdom, we describe algae, bryophytes, pteridophytes, gymnosperms and angiosperms.

2 CLASSIFICATION SYSTEMS

ARTIFICIAL

- Used only gross superficial morphological characters like habit, colour, number and shapes of leaves etc.
- Based mainly on vegetative characters or on the androecium structure (system given by Linnaeus).

LIMITATIONS

- Separated closely related species as they were based on a few characteristics.
- It gave equal weightage to vegetative and sexual characters. This is not acceptable because vegetative characters are more easily affected by environment.

NATURAL

- Based on natural affinities among organisms and consider both external and internal features, like
  - Ultrastructure
  - Anatomy
  - Embryology
  - Phytochemistry
- Such a classification for flowering plants was given by George Bentham and Joseph Dalton Hooker

PHYLOGENETIC

- Based on evolutionary relationship between the various organisms.
- This assumes that organisms belonging to the same taxa have a common ancestor.

3 BRANCHES OF TAXONOMY

NUMERICAL TAXONOMY

- Carried out using computers. Based on observable characteristics.
- Number and codes are assigned to all characters and then data are processed.
- Each character is given equal importance and at the same time hundreds of characters can be considered.

CYTOTAXONOMY

- Based on cytological information like chromosome number, structure and behaviour.

CHEMOTAXONOMY

- Uses chemical constituents of the plants to resolve confusions.

- (These become more important when there is no supporting fossil evidence)

4 ALGAE

- Algae are chlorophyll bearing, simple, thalloid, autotrophic and large aquatic (both fresh water and marine) organisms.
- They occur in variety of other habitats like moist stones, soil & wood.
- Some occur in association with fungi (lichen) & animals (e.g. on sloth bear).
- **Form and size** is highly variable, from colonial (*Volvox*) to filamentous (*Ulothrix* and *Spirogyra*) to massive plant bodies (**marine forms like Kelps**) to unicellular form (*Chlamydomonas*).
- Algae can reproduce by vegetative (**fragmentation**), asexual and sexual means.
- Asexual reproduction – by formation of different types of spores. Most common is zoospore.
- Sexual reproduction 1. ISOGAMOUS = Gametes are similar in size
  - (I) Flagellated gametes e.g. *Ulothrix*
  - (ii) Non -flagellated gametes e.g. *Spirogyra*
  2. ANISOGAMOUS = Gametes dissimilar in size e.g. *Eudorina*
  3. OOGAMOUS = Fusion between one large non-motile female gamete and a smaller male gamete. e.g. *Volvox, Fucus*

ECONOMIC IMPORTANCE

- At least a half of the total CO_2 fixation on earth is carried out by algae.
- Being photosynthetic they increase the level of dissolved oxygen in their immediate environment.
- They are primary producers of energy-rich compounds which form the basis of food cycles of all aquatic animals.
- Many species of *Porphyra*, *Laminaria* and *Sargassum* are among 70 species of marine algae used as food.
- HYDROCOLLOIDS like algin (brown algae) and carrageen (red algae) are used commercially.
- Agar obtained from *Gelidium* and *Gracilaria* are used to grow microbes and in preparations of ice-creams and jellies.
- *Chlorella* are rich in proteins and used as food supplement even by space travellers.

5 THE THREE MAIN CLASSES OF ALGAE

CHLOROPHYCEAE

- Usually grass-green due to dominance of Chl- a & b. Commonly called green algae.
- Pigments are localised in definite chloroplasts.
- Most members have one or more storage bodies in the chloroplasts called pyrenoids, which contain protein & starch.
- Have rigid cell-wall made of inner-cellulose and outer layer of pectose.
- Sexual reproduction may be isogamous, anisogamous or oogamous.
- Eg *Chlamydomonas, Volvox, Ulothrix*, *Spirogyra, Chara*. etc.

PHAEOPHYCEAE

- Found primarily in marine habitats.
- Commonly called brown algae.
- Possess chl- a, c; carotenoids and xanthophylls.
- Olive green to various shades of brown depending on amount of xanthophyll pigment fucoxanthin.
- Food storage as laminarin and mannitol
- Cellulosic cell wall covered by algin.
- Plant body usually has holdfast, stipe and frond.
- In most brown algae pear shaped biflagelled zoospores have two unequal laterally attached flagella.
- Sexual reproduction may be isogomous, anisogamous or oogamous.
- Gametes pyriform with two laterally attached flagella.
- *Eg. Ectocarpus*, *Dictyota, Laminaria, Sargassum, Fucus etc.*

RHODOPHYCEAE

- Red algae have predominance of red pigment r-phycoerythrin in their body.
- Possess chl-a and d.
- Majority are marine with greater concentrations found in warmer areas.
- Occur both in well-lighted regions close to water surface or at great depth in ocean where little light penetrates.
- Cell wall is made up of cellulose, pectin and polysulphated esters.
- Mostly multicellular with some having complex body organisation.
- Food stored as floridean starch, very similar to amylopectin and glycogen in structure.
- Asexual spores and gametes are non-motile
- Sexual reproduction is oogamous and accompanied by complex post fertilisation developments.
- Eg. *Polysiphonia, Porphyra, Gracilaria Gelidium* etc.

6 BRYOPHYTES (Mosses and Liverworts)

- Bryophytes commonly grow in moist shaded area in the hills.
- Called Amphibians of plant kingdom, because these plants can live in soil but are dependent on water for sexual reproduction.
- Rhizoids may be unicellular or multicellular.
- Main plant Body is haploid (gametophyte)
- Multicellular sex organ (♂ antheridium &♀ archegonium)
- Antherozoids are biflagellated.
- Some mosses provide food for herbaceous mammals, bird & other animals.
- Species of *Sphagnum* provide peat used as fuel and as packing material for trans-shipment of living material as they hold water.
- Mosses (along with Lichens) are of great ecological importance, they decompose rocks making substrate suitable for growth of higher plants. They play an important role in plant succession on bare rocks/soil.
- Mosses form dense mats on soil, reduce the impact of falling rain and prevent soil erosion.

BRYOPHYTES ARE DIVIDED INTO

LIVERWORTS

- Plant body thalloid.
- Thallus dorsi-ventral, appressed to the substrate.
- Leafy members have tiny leaf-like appendages in two rows on stem-like structures.
- Asexual reproduction is by fragmentation and gemmae.
- Gemmae are green, multicellular, asexual buds formed in gemma cups located on thalli.
- Sporophyte is differentiated into a foot, seta and capsule. After meiosis spores are produced in the capsule, which germinate to produce free-living gametophytes. Eg. *Marchantia.*

MOSSES

- Gametophytes consist of two stages
  1. Protonema; 2. Leafy-stage
- **Protonema stage:** develops directly from a spore. Protonema is creeping, green, branched and frequently filamentous stage.
- **Leafy stage:** develops from secondary protonema as a lateral bud. They consist of upright, slender axes bearning spirally arranged leaves, attached to the soil through multi-cellular branched rhizoids. It also bears sex-organs.
- **Vegetative reproduction:** by fragmentation and budding in secondary protonema.
- Sporophyte in mosses is more elaborate than in liverworts. They have more elaborate mechanism of spore dispersal.
- **Eg:** *Funaria, Polytrichum* and *Sphagnum*.

7 PTERIDOPHYTES (Horsetails and Ferns)

- Evolutionarily, they are the first terrestrial plants with vascular tissues.
- Found in cool, damp, shady places, though some flourish in sandy-soil.
- Main plant body is sporophyte (2n), with true root, stem and leaves.
- Leaves are small (microphylls) as in *Selaginalla* or large (macrophylls) as in ferns.
- Sporophytes bear sporangia subtended by sporophyll, which may be compact called strobili or cones, as in *Selaginella*, *Equisetum*.

$$\underset{(2n)}{\text{Sporangia}} \rightarrow \underset{(2n)}{\text{Sporemother Cell}} \xrightarrow{\text{Meiosis}} \underset{(n)}{\textbf{Spores}}$$

- Spores germinate to produce inconspicuous, small, multi-cellular, free-living, mostly photosynthetic thalloid gametophytes called prothallus.
- Gametophytes need cool, damp, shady places to grow. This specific requirement and need of water for fertilisation limit the spread of living pteridophytes and restricted to narrow geographical regions.
- Male and female sex organs are antheridia and archegonia.
- Majority are homosprous, but genera like *Selaginella* and *Salvinia* are heterosporous. In heterosporous species the female gametophytes are retained on the parent sporophyte. Zygote develops into young embryos within female gametophytes.
  This event is a precursor to seed habit, considered an important step in *Evolution.*
- Used for medicinal purposes and as soil binders, also grown as ornamentals.
- Pteridophytes are further classified into four classes:
  1. **Psilopsida** - *Psilotum*
  2. **Lycopsida** - *Selaginella*, *Lycopodium*
  3. **Sphenopsida** - *Equisetum*
  4. **Pteropsida** - *Dryopteris*, *Pteris*, *Adiantum*

8 GYMNOSPERMS (Gymnos = naked, sperma = seed)

- Plants in which ovules are not enclosed by ovary wall and remain exposed both before and after fertilisation. Seeds that develop post-fertilisation are naked.
- Gymnosperms include medium-sized or tall trees and shrubs.
- The giant redwood tree *Sequoia* is one of the tallest tree species.
- **Roots:** generally tap roots, having fungal association as mycorrhiza *(Pinus)* or coralloid root with N_2-fixing cyanobacteria as in *Cycas*.
- **Stem:** Branched (*Pinus*; *Cedrus*), Unbranched (*Cycas*)
- **Long and Dwarf shoot:** in *Pinus* and *Ginkgo*.
- **Leaf:** Simple *(Pinus)*; pinnate compound (*Cycas*).
- Leaves are well-adapted to withstand extreme temperature, humidity and wind. In the conifers, needle-like leaves reduce surface area. Thick cutile and sunken stomata help to reduce water loss.
- Gymnosperms are heterosporous
- Sporophylls → Microsporophylls → Male cone/strobili/lax
  Megasporophylls → Female cone/strobili
- Male and female sporangia borne on microsporophylls and megasporphylls respectively.
- Sporangia → Microsporangia (2n) → Pollen grain (n)
  Megasporangia/Ovule (2n) —Meiosis of MMC→ 4 Megaspores
  ↓
  one develops into **Female gametophyte/Endosperm** (n)
- *Pinus* is monoecious, i.e., male and female cone or strobili are borne on same tree; *Cycas is dioecious, i.e.,* male cone and megasporophylls are borne on different trees. (Female cone is absent in *Cycas*).
- Male gametophyte, *i.e.,* pollen grains are highly reduced and confined to limited number of cells.
- Female gametophytes bear two or more archegonia or female sex organs. The multicellular female gametophyte is retained within megasporangium.
- Male and female gametophytes do not have an independent free living existence.
- Pollen grains are carried by air currents and come in contact with opening of ovules.
- Fertilisation is by pollen-tube formation which carries male gametes. Zygote forms embryo and ovules form naked seeds.

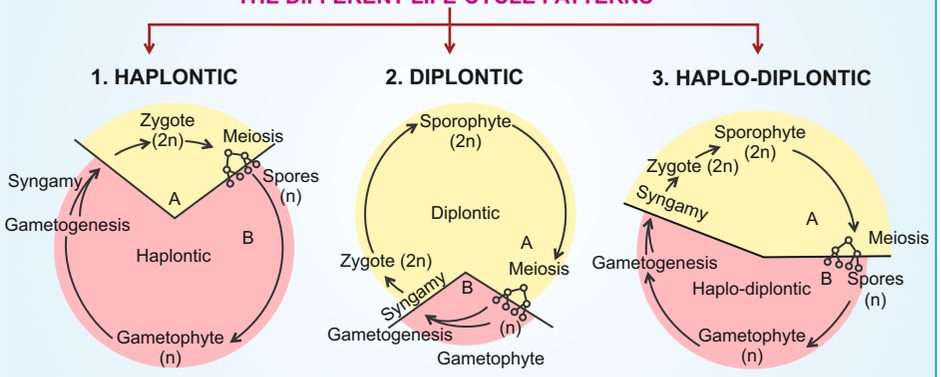
9 ANGIOSPERMS

- In angiosperms or the flowering plants, pollen grains and ovules develop in specialised structures called flowers. Seeds are enclosed in fruits.
- Angiosperms are an exceptionally large group of plants occurring in wide range of habitats.
- Smallest angiosperm is *Wolffia*.
- They are divided into two classes: Dicots having seeds with two cotyledons, reticulate venation in leaf and tetra or pentamerous flowers and Monocots having single cotyledon seed, parallel venation in leaves and trimerous flowers.
- Pollination is by wind or various other agencies.
- Double-fertilisation is unique to the angiosperms. Syngamy produces zygote and triple-fusion produces triploid primary endosperm nucleus (PEN).
- Zygote develops in embryo (with one or two cotyledons) and PEN develops into endosperm (3n) which provides nourishment to the developing embryo. The ovules develop into seeds and the ovaries develop into fruits.

10 PLANT LIFE-CYCLES AND ALTERNATION OF GENERATIONS

- In plants both haploid and diploid cells can divide by mitosis, which leads to the formation of haploid and diploid plant bodies.
- The haploid plant body produces gametes by mitosis, so called gametophytes.
- After fertilisation zygote also divides by mitosis to produce diploid sporophyte plant body.
- Haploid spores are produced by the sporophyte by meiosis which divide to form haploid body again, thus there is alternation of generation between haploid gametophyte and spore producing sporophyte during sexual reproduction in plants.

THE DIFFERENT LIFE-CYCLE PATTERNS



1. **HAPLONTIC:** Sporophytic generation represented only by single-cell zygote. There are no free living sporophytes. Meiosis in zygote produces haploid spores, which divide mitotically to form dominant, photosynthetic free-living gametophyte.
   E.g., Many algae such as *Volvox, Spirogyra* and some species of *Chlamydomonas*.
2. **DIPLONTIC:** Sporophyte dominant, free-living and photosynthetic. The gametophytic phase is represented by single to few-celled gametophyte.
   E.g., All seed bearing plants, *i.e.,* gymnosperms and angiosperms and alga like *Fucus* sp.
3. **HAPLO-DIPLONTIC:**
   (a) Gametophyte dominant, independent, photosynthetic which alternates with totally or partially dependent sporophyte *e.g.,* All bryophytes.
   (b) Sporophyte dominant, independent, photosynthetic, vascular which alternates with saprophytic/autotropic independent but short-lived gametophyte.
   e.g., All pteridophytes
   - Some alga like *Ectocarpus, Polysiphonia,* Kelps are also haplodiplontic.

Sharpen Your Understanding

1. Artificial system of classification based on androecium structure was given by [NCERT Pg. 29]
   (1) Linnaeus
   (2) George Bentham
   (3) Joseph Hooker
   (4) R.H. Whittaker
2. Natural classification systems were based on [NCERT Pg. 29]
   (1) Evolutionary relationships
   (2) Only external features
   (3) Natural affinities among organisms
   (4) Superficial features
3. Chemical constituents of the plants are used to resolve confusion by taxonomists these days. It comes under [NCERT Pg. 30]
   (1) Phylogenetic system
   (2) Cytotaxonomy
   (3) Karyotaxonomy
   (4) Chemotaxonomy
4. The classification system which assumes that organisms belonging to the same taxa have a common ancestor is a [NCERT Pg. 30]
   (1) Natural system
   (2) Artificial system
   (3) Phylogenetic system
   (4) System based on chromosome number

NCERT Based MCQs

5. Which of the following algae shows isogamous sexual reproduction with flagellated gametes? [NCERT Pg. 30]
   (1) *Spirogyra*
   (2) *Ulothrix*
   (3) *Volvox*
   (4) *Fucus*
6. Hydrocolloids like algin are produced by [NCERT Pg. 32]
   (1) Brown algae
   (2) Red algae
   (3) Green algae
   (4) Blue-green algae
7. Agar a commercial product used to grow microbes and in ice-creams and jellies are obtained from [NCERT Pg. 32]
   (1) *Gelidium* and *Gracilaria*
   (2) *Chlorella* and *Volvox*
   (3) *Ectocarpus* and *Dictyota*
   (4) *Polysiphonia* and *Fucus*
8. Pyrenoids, the storage bodies located in the chloroplasts of most members of chlorophyceae contain protein besides [NCERT Pg. 32]
   (1) Glycogen
   (2) Starch
   (3) Cellulose
   (4) Amylopectin
9. Members of phaeophyceae vary in colour from olive green to various shades of brown depending upon the amount of the pigment [NCERT Pg. 32]
   (1) Chl- a & b
   (2) Chl-d
   (3) Fucoxanthin
   (4) r-phycoerythrin
10. Gametes are pear-shaped and bear two laterally attached flagella in [NCERT Pg. 33]
    (1) *Polysiphonia*
    (2) *Porphyra*
    (3) *Gelidium*
    (4) *Dictyota*
11. Polysulphate esters are found in the cell wall of [NCERT Pg. 33]
    (1) Green algae
    (2) Brown algae
    (3) Red algae
    (4) Golden-brown algae
12. The creeping, green, branched, frequently filamentous stage of the gametophyte of mosses, which develops directly form spore is called [NCERT Pg. 36]
    (1) Leafy stage
    (2) Secondary protonema
    (3) Primary protonema
    (4) Prothallus

13. Bryophytes are called amphibians of the plant kingdom because [NCERT Pg. 35]
(1) They live on soil but depend on water for sexual reproduction
(2) They have main plant body as gametophyte
(3) They occur in humid and shaded localities
(4) They play important role in plant succession

14. The inconspicuous, small, multi-cellular, free-living mostly photosynthetic thalloid gametophytes produce in pteridophytes is called [NCERT Pg. 38]
(1) Strobilus (2) Protonema
(3) Prothallus (4) Gemmae

15. Which of the following genera of pteridophytes is heterosporous? [NCERT Pg. 38]
(1) *Equisetum* (2) *Salvinia*
(3) *Pteris* (4) *Psilotum*

16. The coralloid roots of *Cycas* are associated with N_2-fixing [NCERT Pg. 38]
(1) Fungi (2) *Rhizobium*
(3) Mycorrhiza (4) Cyanobacteria

17. In monocotyledons flowers are mainly [NCERT Pg. 40]
(1) Trimerous
(2) Pentamerous
(3) Tetramerous
(4) Hexamerous

18. The smallest angiosperm is [NCERT Pg. 40]
(1) *Eucalyptus* (2) *Zamia*
(3) *Wolffia* (4) *Hydrilla*

19. Which of the following algae shows haplo-diplontic life cycle pattern? [NCERT Pg. 43]
(1) *Fucus*
(2) *Chlamydomonas*
(3) *Polysiphonia*
(4) *Volvox*

20. All seed-bearing plants show which of the following life-cycle pattern? [NCERT Pg. 42]
(1) Haplontic (2) Diplontic
(3) Haplo-diplontic (4) Both (1) and (3)

Thinking in Context

1. _____ is carried out using computers and is based on all observable characters. [NCERT Pg. 30]

2. Cytotaxonomy is based on _____ like chromosome number, structure and behaviour. [NCERT Pg. 30]

3. In algae, the most common asexual spore is _____. [NCERT Pg. 30]

4. _____ is unicellular alga rich in proteins, which is used as food supplement even by space travellers. [NCERT Pg. 32]

5. At least a half of the total _____ on earth is carried out by algae through photosynthesis. [NCERT Pg. 32]

6. Members of chlorophyceae are usually grass-green in colour due to the dominance of pigments _____. [NCERT Pg. 32]

7. Food is stored as complex carbohydrates, which may be in the form of _____ in phaeophyceae i.e., brown algae. [NCERT Pg. 33]

8. Majority of the red algae are marine with greater concentrations found in the _____. [NCERT Pg. 33]

9. The food in red-algae is in the form of _____ which is very similar to amylopectin and glycogen in structure. [NCERT Pg. 33]

10. A along with B are the first organisms to colonise rocks and hence are of great ecological importance. [NCERT Pg. 35]

11. Asexual reproduction in liverworts takes place by the formation of specialized structures called _____. [NCERT Pg. 35]
12. Vegetative reproduction in mosses is by fragmentation and budding in the _____. [NCERT Pg. 36]
13. The gametophytes of pteridophytes require cool, damp, shady places to grow. Because of this specific restricted requirement and need of water for fertilisation. the spread of _____ is limited to narrow geographical regions. [NCERT Pg. 38]
14. In heterosporous pteridophytes, development of the zygotes into young embryo take place within the female gametophytes. This event is a precursor to the _____ considered an important step in evolution. [NCERT Pg. 38]
15. In gymnosperms stems are branched in _____. [NCERT Pg. 38]
16. The gymnosperms are _____, they produce haploid microspores and megaspores. [NCERT Pg. 39]
17. In gymnosperms, the male and the female gametophytes do not have an independent _____. [NCERT Pg. 39]
18. In angiosperms the ovules develop into A and the B develop into fruit. [NCERT Pg. 41]
19. Depending on the A possessed and the type of B , algae are classified into three classes. [NCERT Pg. 43]
20. The main plant body of a Bryophyte is gamete producing and is called a _____. [NCERT Pg. 43]

❑ ❑ ❑

Molecular Basis of Inheritance

4 Chapter

1 INTRODUCTION

- Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are two types of nucleic acid found in living systems. DNA acts as the genetic material in most of the organisms. RNA though it acts as a genetic material in some viruses, like TMV, QB-bacteriophage but mostly functions as a messenger, adaptor, structural and catalytic molecule.

2 THE DNA

- DNA is a long polymer of deoxyribonucleotides. The length of DNA usually defined as number of nucleotides, is also characteristic of an organism.

ORGANISM	DNA CONTENT
1. Bacteriophage $\phi \times 174$	5386 Nucleotides
2. Bacteriophage lambda	48502 base pairs
3. *Escherichia coli*	4.6×10^6 base pairs
4. Haploid content of human DNA	3.3×10^9 base pairs

Structure of Polynucleotide Chain

- The basic unit of a polynucleotide (DNA or RNA) is NUCLEOTIDE – which has 3 components.
  - (i) A Nitrogenous base — PURINES = A (Adenine) and G (Guanine); PYRIMIDINES = C (Cytosine), T (Thymine) and U (Uracil)
  - (ii) A Pentose sugar — RIBOSE (In RNA); 2-DEOXYRIBOSE (in DNA)
  - (iii) A Phosphate group
- Purines are same in DNA and RNA, cytosine is common to both DNA and RNA, Uracil is present in RNA, Thymine (5-methyl uracil) in DNA
- A nitrogenous base is linked to the OH of 1′C pentose sugar through a N-glycosidic linkage to form a **NUCLEOSIDE**
- When a phosphate group is linked to OH of 5′C of a nucleoside through phosphoester linkage, a corresponding NUCLEOTIDE is formed.
- Two nucleotides are linked through 3′-5′ phosphodiester linkage to form a DINUCLEOTIDE. More nucleotides in such a manner form polynucleotide.
- A polymer thus formed has at one end a free phosphate moiety at -5′- end of sugar and at the other end of polymer the sugar has a free OH of 3′ C group

3 DNA-DOUBLE HELIX

- DNA as an acidic substance present in nucleus was first identified by Friedrich Miescher in 1969, named it as "Nuclein'.
- Based on the X-ray diffraction data produced by Maurice Wilkins and Rosalind Franklin, James Watson and Francis Crick proposed a very simple but famous double helix model of DNA in 1953.
- One hallmark of the helix is base pairing between the two strands. Based on the observation of Erwin Chargaff that for a double stranded DNA, the ratios between A and T and G and C are constant and equals one. The base-pairing confers COMPLEMENTARITY, a unique property to the polynucleotide chain.
- So, if each strand of parental DNA, acts as a template for synthesis of a new strand, the two double stranded daughter DNA produced would be identical to the parental DNA molecule.

Salient Features of Double-helix of DNA

- Made of two polypeptide chains, where the backbone is constituted by sugar - phosphate and bases project inside.
- Two chains have anti-parallel polarity, one chain $5' \rightarrow 3'$, the other $3' \rightarrow 5'$
- Bases in two strands are paired through hydrogen bonds, forming base pairs. (A = T and C ≡ G). This generates approximately uniform distance between the two strands.
- The two chains are coiled in a right handed fashion.
- Pitch of the helix = 3.4 nm. Roughly 10 bp in each turn. So, distance between a bp in a helix is approx. 0.34 nm. (0.34×10^{-9} m)
- The plane of one base pair stacks over the other in double-helix. This in addition to H-bonds, confers stability to the helical structure.

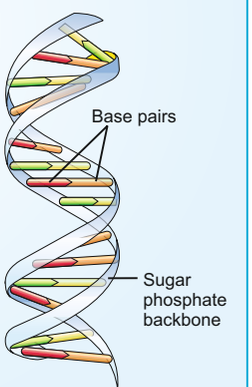


Fig. : DNA double helix.

4 CENTRAL DOGMA OF MOLECULAR BIOLOGY : Proposed by FRANCIS CRICK.

- States flow of genetic information as DNA → RNA → Protein

DNA (Replication) —TRANSCRIPTION→ mRNA —TRANSLATION→ Protein

In some viruses the flow of information is in reverse direction, i.e. from RNA to DNA. It is called reverse of central dogma.

5 PACKAGING OF DNA HELIX

- DNA double helix in a typical mammalian cell is 6.6×10^9 bp, the length is approx 2.2 m (6.6×10^9 bp $\times$ 0.34×10^{-9} m/bp), far greater than the dimension of a typical nucleus (approx 10^{-6}m)
- In prokaryote (*E. coli*), the DNA being negatively charged is held with some proteins that have positive charges in the 'NUCLEOID'. The DNA in nucleoid is organised in large loops held by proteins.

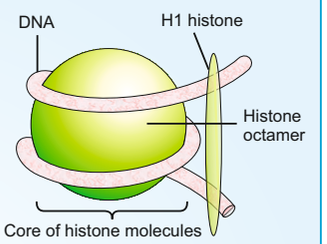


Fig.: Nucleosome

- In eukaryotes, it is much more complex.
  - (i) The positively charged set of basic proteins, HISTONES (rich in lysine and arginine) are organised to form a unit of eight molecules, called **HISTONE OCTAMER**
  - (ii) The negatively charged DNA is wrapped around positively charged histone octamer to form a nucleosome. A typical nucleosome contains 200 bp of DNA helix.
- Nucleosomes constitute the repeating unit of a structure in nucleus called CHROMATIN, thread like stained bodies seen in nucleus. The nucleosomes in chromatin are seen as 'beads - on - string' structure under electron microscope. It is packaged to form chromatin fibers that are further coiled and condensed at metaphase stage to form chromosomes.
- Packaging of chromatin at higher level needs non-histone chromosomal (NHC) proteins.

In a typical NUCLEUS (regions of chromatin)

EUCHROMATIN	HETEROCHROMATIN
1. Loosely packed.	1. More densely packed
2. Stains light	2. Stains dark
3. Transcriptionally active	3. Transcriptionally inactive

6 THE SEARCH FOR GENETIC MATERIAL

Transforming Principle

- In 1928, Frederick Griffith, in a series of experiments with *Streptococcus pneumoniae*, witnessed a miraculous transformation in Bacteria.
- Some of these bacteria produce smooth shiny colonies (S) while others rough colonies (R). S-strain kills mice (virulent) while R-strain do not develop pneumonia. But heat killed S-strain are also non-virulent. When heat killed S and live R bacteria were injected in mice, the mice died and S-strain living bacteria were found in dead mice. Griffith concluded that R-strain was somehow transformed by heat-killed S - strain. It must be due to the transfer of genetic material (transforming principle). But the biochemical nature was not defined.

Biochemical Nature of Transforming Principle

- Oswald Avery, Colin MacLeod and Maclyn McCarty (1933-44) discovered that DNA of S bacteria caused R bacteria to become transformed. As proteases and RNAses did not affect transformation, but DNAse inhibit transformation. They concluded that DNA is the hereditary material. But not all biologists were convinced.

The Genetic Material is DNA

- The UNEQUIVOCAL proof that DNA is the genetic material came from the experiments of Alfred Hershey and Martha Chase (1952), on bacteriophages, using radioactive phosphorus ^{32}P and sulphur ^{35}S in separate medium, with *E. coli*.

7 PROPERTIES OF GENETIC MATERIAL (DNA VERSUS RNA)

A molecule that can act as a genetic material must fulfill the following criteria:

(i) Should be able to generate its replica (Replication)
(ii) Should be stable chemically and structurally
(iii) Should provide the scope for slow mutation required for evolution.
(iv) Should be able to express in the form of Mendelian characters.

- Both DNA and RNA can direct their duplications.
- The DNA has two complementary strands, if separted by heating can again come together when appropriate conditions are provided.
- 2′-OH group present at every nucleotide in RNA is reactive and makes it easily degradable.
- RNA is also catalytic, hence reactive. Among the two nucleic acids, DNA is a better genetic material.
- Presence of thymine at the place of uracil also confers additional stability to DNA
- Both DNA and RNA are able to mutate. Being unstable RNA mutate at a faster rate.
- RNA can directly code for the synthesis of proteins and can easily express the characters. DNA, however is dependent on RNA for synthesis of proteins.
- DNA being more stable is preferred for storage of genetic information. For transmission of genetic information RNA is better.

8 RNA WORLD

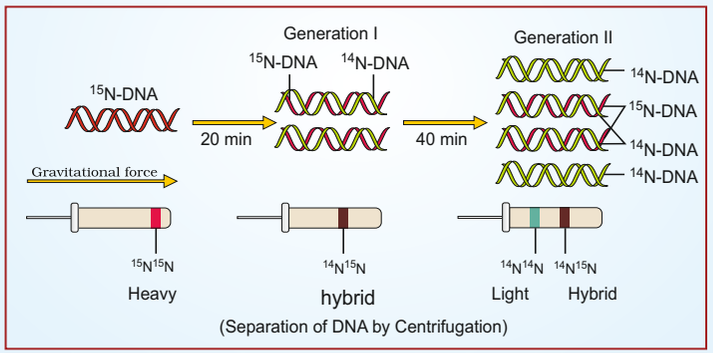
RNA was the first genetic material. The essential life processes like metabolism, translation, splicing evolved around RNA. RNA used to act as a genetic material as well as a catalyst, so was reactive and hence unstable. Therefore, DNA has evolved from RNA with chemical modifications that make it more stable.

9 REPLICATION

Watson and Crick had immediately proposed a scheme for replication of DNA while proposing the double helix structure of DNA, i.e., the two strands would separate and act as a template for the synthesis of new complementary strands. After completion of replication each DNA molecule would have one parental and one newly synthesised strand, termed as semi-conservative DNA replication

10 EXPERIMENTAL PROOF

- Semiconservative DNA replication was shown first in *Escherichia coli*, then in higher organisms like plants and human cells.
- Matthew Meselson and Franklin Stahl, performed the experiment (1958) using normal ^{14}N and non-radioactive ^{15}N isotope of Nitrogen as source of NH_4Cl, and centrifugation in a cesium chloride (CsCl) density gradient. The various samples were separated independently on CsCl gradients to measure the densities of DNA. (*E. coli* divides every 20 minutes)



(Separation of DNA by Centrifugation)

- Taylor and colleagues (1958) used radioactive thymidine and *Vicia faba* (Faba beans), to prove that DNA in chromosomes also replicate semi-conservatively.

11 THE MACHINERY AND THE ENZYMES

- *E. coli* completes replication in 18 minutes. The average rate of polymerisation is 2000 bp/sec.
- Energetically replication is a very expensive process.

Deoxyribo nucleoside triphosphates — Serve / Dual purpose
- (1) Act as substrate
- (2) Provide energy for polymerisation

- Replication occur within a small opening of DNA helix called replication fork.

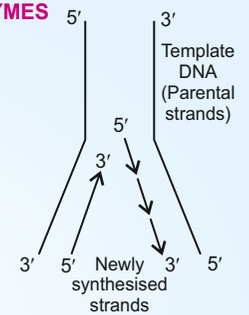


Fig: Replicating Fork

- DNA-dependent DNA polymerase (main enzyme) catalyses the polymerisation process in 5′ → 3′ direction, so on one strand (template with polarity 3′ → 5′) replication is continuous, while on other (template with polarity 5′ → 3′) it is dis-continuous.
- Discontinuously synthesised fragments are later joined by DNA ligase.
- There is a definite region in *E. coli* DNA where replication originates is termed ori-site (origin of replication).
- During recombinant DNA procedures, requires a vector, which provide origin of replication.
- In eukaryotes, replication of DNA takes place at S-phase of the cell-cycle.

Replication of DNA and cell-division cycle should be highly co-ordinated. A failure in cell-division after DNA replication results in POLYPLOIDY (Chromosomal anomaly)

12 TRANSCRIPTION

- It is process of copying genetic information from one strand of DNA into RNA.
- Principle of complementarity governs transcription (except, adenosine forms pair with uracil instead of thymine). In transcription only a segment of DNA and only one of the two strands is copied into RNA. Otherwise, one segment of DNA would be coding for two different proteins. Also, the two RNA molecules if produced simultaneously would be complementary to each other, hence would form a double stranded RNA. This would prevent translation.

TRANSCRIPTION UNIT : A transcription unit in DNA primarily has three regions

(i) A promoter
(ii) The structural gene
(iii) A terminator

- The DNA-dependent RNA polymerase catalyses polymerisation in only one direction 5′ → 3′. The strand that has polarity 3′ → 5′ act as a template. The other strand with polarity 5′ → 3′ and the sequence same as RNA (except thymine at place of uracil), is referred to as coding strand.

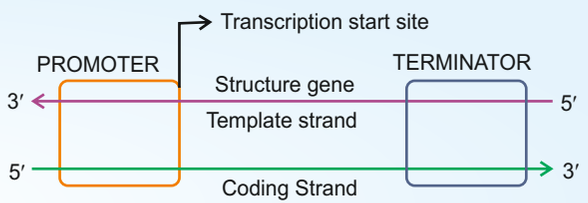


Fig: A transcription Unit

- Promoter is located towards 5′-end (upstream) of structural gene (in reference to coding strand). It provides binding site for RNA polymerase.
- Terminator is located towards 3′-end (downstream) of coding strands and defines end of transcription.

13 TRANSCRIPTION UNIT AND THE GENE

- Genes are located on the DNA which is functional unit of inheritance. DNA sequence coding for tRNA or rRNA also define a gene.
- Cistron is defined as a segment of DNA coding for polypeptide.
- The structural gene is monocistronic (mostly in Eukaryotes) or polycistronic (mostly in bacteria or prokaryotes). In Eukaryote genes are split between coding sequences or EXONS, which appear in mature RNA and INTRONS or intervening sequence. The split gene arrangement further complicates the definition of a gene in terms of a DNA segment. Regulatory sequences are defined as regulatory genes, even though they do not code for any RNA or protein.

TYPES OF RNA AND THE PROCESS OF TRANSCRIPTION

- A single DNA dependent RNA polymerase catalyses transcription of all three types of RNA (mRNA, tRNA, rRNA) in bacteria.
- RNA polymerase binds to promoter and initiates transcription. It uses nucleoside triphosphates as substrate and polymerises in a template depended fashion following the rule of complementarity. It somehow also facilitates opening of the helix and continues elongation.
- Only a short stretch of RNA remains bound to the enzyme. Once the polymerase reaches the terminator region, the nascent RNA and RNA polymerase falls off. This results in termination of transcription.
- RNA polymerase is only capable of catalysing the elongation process. It associates transiently with initiation factor (σ) and termination factor (ρ) to initiate and terminate the transcription respectively.
- In bacteria, mRNA does not require any processing, so transcription and translation are coupled. In Eukaryotes, there are two additional complexities.

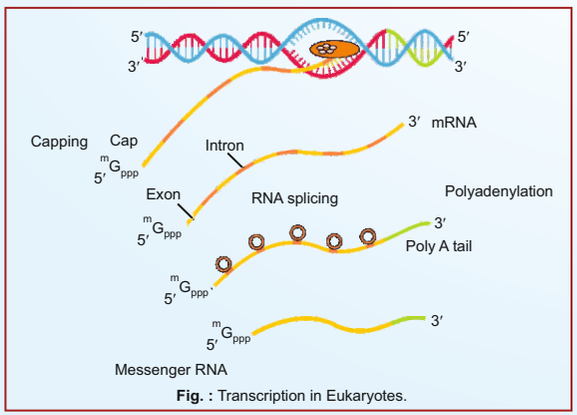


Fig. : Transcription in Eukaryotes.

- There are at least three RNA polymerase in the nucleus (in addition to RNA polymerase found in organelles) and a clear cut division of labour.

ENZYME	FUNCTIONS
1. RNA pol-I	Transcribes 28S, 5.8S and 18S rRNA
2. RNA pol-II	Transcribes mRNA precursor i.e. hn-RNA
3. RNA pol-III	Transcribes 5S rRNA, tRNA and Sn RNAs

- The primary transcript (hn RNA) is subjected to SPLICING, where INTRONS are removed and EXONS are joined in a defined order. hn-RNA undergoes additional processing called capping and tailing to form mRNA. In CAPPING an unusual nucleotide (methyl guanosine triphosphate) is added to 5′ -end of hn RNA. In TAILING, adenylate residues (200-300) are added to 3′-end in a template independent manner. Fully processed hn-RNA is called m-RNA that is transported out of the nucleus for TRANSLATION. The split-gene arrangement represent probably an ancient feature of the genome. The presence of introns is reminiscent of antiquity, and the process of splicing represents the dominance of RNA-world.

14 GENETIC CODE

- George Gamow, suggested, that the genetic code should be triplet.
- Chemical method developed by Har Gobind Khorana was instrumental in synthesising RNA molecules with defined combinations of bases. Marshall Nirenberg's cell-free system for protein synthesis finally helped the code to be deciphered. Severo Ochoa enzyme (Polynucleotide phosphorylase) was helpful in polymerising RNA with defined sequences in a template independent manner (enzymatic synthesis of RNA)

Salient Features of Genetic Code :

- The codon is Triplet. 61 codons code for amino acids and 3 codons are stop codons.
- The code is DEGENERATE, i.e., some amino acids are coded by more than one codon.
- The codon is read on mRNA in contiguous fashion i.e., there are no punctuations.
- The code is nearly universal. (eg : UUU codes for phenylalanine from bacteria to humans). Exception = some variations have been found in mitochondrial codons and in some protozoans.
- AUG has dual function. It codes for methionine and act as initiator codon.
- UAA, UAG and UGA are stop terminator codons.

15 MUTATIONS AND GENETIC CODE

- Insertion or deletion of one or two bases changes the reading frame from the point of insertion or deletion and called frame shift mutations.
- Insertion or deletion of three or its multiple base, insert or delete in one or multiple codon hence one or multiple amino acids, and reading frame remains unaltered from that point onwards.

tRNA- the Adapter Molecule

- Francis Crick postulated the presence of an adapter molecule, that would read the code and bind to specific amino acid. The tRNA, then called sRNA (soluble RNA) was known before genetic code was postulated. tRNA has an anti-codon loop that has bases complementary to the code, and it also has an amino acid acceptor end to which it binds to amino acids. tRNAs are specific for each amino acid. For initiation, there is another specific tRNA that is called **initiator tRNA**. There are no tRNAs for stop codons.
- Secondary structure of tRNA looks like a cloverleaf, though the actual structure is a compact molecule which looks like inverted L.

16 TRANSLATION

- Translation refers to the process of polymerisation of amino-acids to form a polypeptide. The order and sequence of amino-acids are defined by the sequence of bases in the mRNA.
- In the first phase amino acids are activated in the presence of ATP and linked to their cognate tRNA by a process called **charging of tRNA,** or **aminoacylation of tRNA**. Protein synthesis takes place on the ribosomes.
- Ribosomes consist of structural RNAs and about 80 different proteins. It has two sub-units. When the small sub unit encounters an mRNA, the process of translation begins. There are two sites in the large subunit, for subsequent amino acids to bind and thus, be close enough to each other for the formation of a peptide bond by the catalyst (23 S rRNA in bacteria is the enzyme- ribozyme). Presence of catalyst would enhance the rate of peptide bond formation.
- A translational unit in mRNA is flanked by a start condon (AUG) and the stop codon. The untranslated additional sequence on mRNA are called untranslated regions, (UTRs), present at both 5′-end (before start codon) and at 3′- end (after stop codons). UTRs are required for efficient translation.
- The ribosome moves from codon to codon along the mRNA. Amino acids are added one by one and translated into polypeptide sequences. At the end, a release factor binds to the stop codon, terminating translation and releasing the complete polypeptide from the ribosome.

17 REGULATION OF GENE EXPRESSION

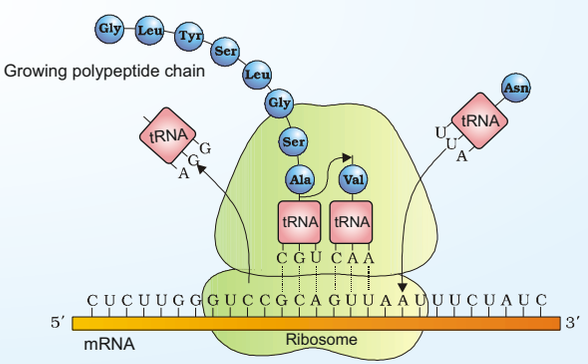
Gene expression results in formation of a polypeptide. It can be regulated at several levels. In Eukaryotes, the regulation could be exerted at

(i) Transcriptional level (Formation of primary transcript)
(ii) Processing level (Regulation of Splicing)
(iii) Transport of mRNA from nucleus to cytoplasm.
(iv) Translational level

- Metabolic, physiological or environmental conditions regulate expression of genes.
- Development and differentiation of embryo into adult organisms are also a result of the coordinated regulation of expression of several set of genes.
- In prokaryotes, control of the rate of transcriptional initiation is the predominant site for control of gene expression.

18 THE *Lac* OPERON

- Francois Jacob and Jacque Monod were the first to elucidate a transcriptionally regulated system, the *lac* operon (*lac* refers to lactose), a polycistronic structural gene regulated by a common promoter and regulatory gene, called operon.
- Lac operon consists of one regulatroy gene (i) and three structural genes (z, y and a). i gene (i refers inhibitor) codes for repressor, z-for β-galactosidase (β-gal), y-for permease and gene a codes for transacetylase. All three gene products in lac operon are needed for metabolism of lactose.
- Lactose is the substrate of β-galactosidase and it regulates switching on/off of operon, so called INDUCER. Regulation of *lac* operon is regulation of enzyme synthesis by its substrate.
- Regulation of *lac* operon by repressor is negative regulation however *lac* operon is under control of positive regulation as well.
- Regulatory proteins can act both positively (activators) and negatively (repressors).
- Each operon has its specific operator and specific repressor.



19 HUMAN GENOME PROJECT - (HGP)

- Launched in 1990, a 13 year project was co-ordinated by U.S. department of energy and National Institute of Health, Wellcome trust (UK), Japan, France, Germany, China participated. It was completed in 2003.
- Human genome has approx. 3×10^9 bp and the cost of sequencing in the beginning was US$3 per bp, i.e. 9 billion US dollars. HGP lead to the rapid development of a new area in biology called bioinformatics.
- Many non-human model organisms like bacteria, Yeast, *Caenorhabditis elegans*, *Drosophila,* plant (rice and *Arabidopsis*) have also been sequenced.

METHODOLOGIES :

- **Expressed sequence tags (ESTs):** Focused on identifying all genes that expressed as RNA.
- **Sequence annotation:** Blind approach of sequencing the whole genome containing coding and non coding sequences; needing vectors like BAC (Bacterial artificial chromosomes) and YAC (Yeast Artificial Chromosomes).

SALIENT FEATURES OF HUMAN GENOME :

- Human genome contains 3164.7 million bp. Average gene consist of 3000 bases.
- Largest gene DYSTROPHIN of 2.4 million bases. Total genes estimated at 30,000.
- Almost 99.9% nucleotide bases exactly same in all people. Functions unknown for 50% discovered genes. Less than 2% genome codes for protein. Chromosome 1 has most genes (2968) and Y-chromosome has the fewest (231).
- At 1.4 million locations single base DNA differences (SNPs - single nucleotide polymorphism, snips) occur. SNPs can help in tracing human history.

- The fragments were sequenced using automated DNA sequencer that worked on the principle of a method developed by Frederick Sanger.
- The sequence of chromosome-1 was completed only in May 2006. This was the last of the 24 human chromosomes (22 autosomes and X and Y) to be sequenced.

20 DNA FINGERPRINTING

- 99.9% base sequence among humans is same. 0.1% differences in sequence of DNA make every individual unique in their phenotype. DNA fingerprinting involves identifying difference in **repetitive DNA**, a small stretch of DNA repeated many times, called satellite DNA. Depending on base composition (A:T or G:C rich), length of segment and number of repetitive units, the satellite DNA is classified into micro-statellites and mini-satellites. They do not code for any proteins. They form large portion of human genome and show high degree of polymorphism and form the basis of DNA fingerprinting. Since DNA from every tissue (blood, hair-follicle, skin, bone, saliva, sperm), show same degree of polymorphism, they have forensic application.
- Polymorphisms are inheritable from parent to child so DNA finger printing solves paternity disputes.
- The technique of DNA finger printing was initially developed by Alec Jeffreys.

Steps = Isolation of DNA (I) → Digestion by restriction endonuclease (II) → Separation of DNA fragments by Electrophoresis (III) → Blotting on nitrocellulose or Nylon membrane (IV) → Hybridisation using labelled VNTR probe (V) → Detection of hydrobised DNA Fragments by AUTORADIOGRAPHY (VI)

Significance

- VNTR are called min-statellite, a small DNA sequence arranged tandemly in many copies. The size of VNTR varies from 0.1 to 20 kb. So after hybridisation with VNTR probe, the autoradiogram gives many bands of differing sizes. These bands give a characteristic pattern for an individual DNA. It differs from individual to individual in a population except in MONOZYGOTIC twins.
- The sensitivity of the technique has been increased by use of polymerase chain reaction (PCR).

21

- The repressor of operon is synthesised (all the time-constitutively from the 'i' gene)
- A very low level of expression of *lac* operon has to be present in the cell all the time otherwise lactose cannot enter the cells. Lactose or allolactose is the inducer of lac operon. Glucose or galactose cannot act as inducers for lac operon.
- Allelic sequence variation has traditionally been described as a DNA polymorphism, if more than one variant (allele) at a locus occurs in human population with a frequency greater than 0.01.
- DNA fingerprinting has much wider application in determining population and genetic diversities. Currently, many different probes are used to generate DNA fingerprints.
- The hallmark of double-stranded helical structure of DNA is the hydrogen bonding between the bases from opposite strands.

Sharpen Your Understanding

1. What is the haploid content of DNA in a typical human cell? [NCERT Pg. 96]
   (1) 6.6×10^9 bp (2) 3.3×10^9 bp
   (3) 48502 bp (4) 4.6×10^6 bp
2. DNA as an acidic substance present in nucleus was first identified and named as 'Nuclein' by [NCERT Pg. 97]
   (1) Maurice Wilkins
   (2) Francis Crick
   (3) Friedrich Miescher
   (4) Rosalind Franklin
3. Who first observed that for a double stranded DNA, the ratios between Adenine and Thymine and Guanine and Cytosine are constant and equals one? [NCERT Pg. 97]
   (1) Erwin Chargaff (2) James Watson
   (3) Rosalind Franklin (4) Frederick Griffith
4. The distance between a base pair in a helix of DNA is approximately : [NCERT Pg. 97-98]
   (1) 3.4 nm (2) 0.34 nm
   (3) 34 nm (4) 20 nm
5. Who proposed the Central Dogma in molecular biology, which states that the genetic information flows from DNA → RNA → Protein? [NCERT Pg. 98]
   (1) James Watson (2) Maurice Wilkins
   (3) Francis Crick (4) Erwin Chargaff
6. Histones are rich is basic amino acid residues like [NCERT Pg. 99]
   (1) Cystine and arginine
   (2) Lysine and arginine
   (3) Alanine and Lysine
   (4) Serine and Lysine
7. In a typical nucleus, the Euchromatin is said to be [NCERT Pg. 100]
   (1) Densely packed
   (2) Transcriptionally inactive
   (3) Transcriptionally active
   (4) Darkly stained
8. Which of the following enzymes, inhibit transformation during the work of Oswald Avery; Colin MacLeod and Maclyn McCarty on the biochemical characterization of transforming principle? [NCERT Pg. 101]
   (1) Proteases (2) DNases
   (3) RNases (4) Lipases
9. The unequivocal proof that DNA is the genetic material came from the experiments of : [NCERT Pg. 101]
   (1) Alfred Hershey and Martha Chase
   (2) Frederick Griffith
   (3) Oswald Avery
   (4) MacLeod and McCarty

NCERT Based MCQs

10. Presence of which of the following nitrogenous bases, at the place of Uracil of RNA confers additional stability to DNA? [NCERT Pg. 103]
    (1) Cytosine (2) Thymine
    (3) Adenine (4) Guanine
11. Taylor and colleagues proved that the DNA in chromosomes of *Vicia faba* also replicate semi-conservatively using. [NCERT Pg. 106]
    (1) ^{15}N radio-isotope
    (2) P^{32} and S^{35} isotopes
    (3) CsCl gradients
    (4) Radioactive thymidine
12. The structural gene in a transcription unit in bacteria or prokaryotes is mostly [NCERT Pg. 109]
    (1) Monocistronic
    (2) Polycistronic
    (3) Intervening sequence
    (4) Exons and Introns
13. The precursor of mRNA, in the eukaryotes is transcribed by [NCERT Pg. 111]
    (1) DNA polymerase
    (2) RNA polymerase-I
    (3) RNA polymerase-II
    (4) RNA polymerase-III

14. Some amino acids are coded by more than one codon, hence the codon is said to be [NCERT Pg. 112]
(1) Universal (2) Triplet
(3) Non degenerate (4) Degenerate

15. A change of single base pair in the gene for beta globin chain that results in the change of amino acid residue glutamate to valine. It results into a diseased condition called as [NCERT Pg. 113]
(1) Sickle cell anemia (2) α-thalassemia
(3) β-thalassemia (4) Haemophilia

16. The secondary structure of tRNA looks like [NCERT Pg. 114]
(1) Inverted L
(2) A clover leaf
(3) A double helix
(4) Straight polypeptide chain

17. Which of the following is a ribozyme in bacteria for the formation of peptide bond? [NCERT Pg. 115]
(1) 28 S rRNA
(2) 5.8 S rRNA
(3) 23 S rRNA
(4) 16 S rRNA

18. Which of the following enzyme is primarily responsible for the hydrolysis of the disaccharide, lactose into its monomeric units galactose and glucose in the ***Lac* operon**? [NCERT Pg. 116]
(1) Beta-galactosidase
(2) Permease
(3) Transacetylase
(4) Tyrosinase

19. The blind approach of simply sequencing the whole set of genome that contained all the coding and non-coding sequence, and later assigning different regions in the sequence with functions is termed as [NCERT Pg. 119]
(1) Bioinformatics
(2) Sequence annotation
(3) EST approach
(4) Transcriptome method

20. Polymorphism, i.e., variation at the genetic level arises due to [NCERT Pg. 121]
(1) Repetitive DNA
(2) Satellite DNA
(3) Mutations
(4) Asexual reproduction

Thinking in Context

1. _____ is the basis of genetic mapping of human genome as well as of DNA fingerprinting. [NCERT Pg. 121]

2. The probability of polymorphism to be observed in non-coding DNA sequence would be _____ as mutations in these sequences may not have any immediate effect/impact in an individual's reproductive ability [NCERT Pg. 122]

3. The VNTR belongs to a class of Satellite DNA referred to as ____. [NCERT Pg. 122]

4. _____ is credited for developing method for determination of amino acid sequences in proteins. [NCERT Pg. 119]

5. HGP was closely associated with the rapid development of a new area in biology called _____ [NCERT Pg. 118]

6. The repressor of the Lac operon is synthesised all the time, i.e., _____ from the *i*-gene. [NCERT Pg. 117]

7. In prokaryotes, control of the rate of _____ is the predominant site for control of gene expression [NCERT Pg. 116]

8. In the first phase of translation itself amino acids are activated in the presence of ATP and linked to their cognate tRNA-a process commonly called as charging of tRNA or _____ to be more specific. [NCERT Pg. 114]

9. For initiation of translation, the ribosome binds to the mRNA at the start codon (AUG) that is recognized only by the _____ [NCERT Pg. 115]

10. _____ postulated the presence of an adapter molecule that would on one hand read the code and on other hand would bind to specific amino-acids. [NCERT Pg. 114]

11. Severo Ochoa enzyme _____ was helpful in polymerizing RNA with defined sequences in a template independent manner. [NCERT Pg. 112]

12. _____ had dual functions, it codes for Methionine, and it also act as initiator codon. [NCERT Pg. 112]

13. In _____, adenylate residues (200-300) are added at 3′ - end in a template independent manner. [NCERT Pg. 111]

14. Exons are said to be those sequence that appear in mature or _____. [NCERT Pg. 109]

15. It is because of the requirement of the _____ that a piece of DNA if needed to be propagated during recombinant DNA procedures, requires a vector. [NCERT Pg. 107]

16. The principle of _____ governs the process of transcription, except the adenosine complements now forms base pair with uracil instead of thymine. [NCERT Pg. 107]

17. The heavy DNA molecule could be distinguished from the normal DNA by the centrifugation in a _____ density gradient. [NCERT Pg. 105]

18. DNA being more stable is preferred for ___A___ of genetic information. For the ___B___ of genetic information, RNA is better. [NCERT Pg. 104]

19. DNA being double stranded and having _____ further resists changes by evolving a process of repair. [NCERT Pg. 104]

20. Stability as one of the properties of genetic material was very evident in Griffiths, 'transforming principle' itself that heat, which killed the bacteria, at least did not destroy some of the properties of _____ [NCERT Pg. 103]

❑ ❑ ❑