Recent studies have shown that DNA of a nucleolus is circular and called *r*DNA (ribosomal DNA) which actively transcribes *r*RNA. Nucleolar DNA is *highly redundant* (highly repetitious type) and is an example of a giant *palindrome* (inverted repeat sequence). There are thousands of copies of *r*RNA genes in it. Each such gene transcribes to form 45 S *r*RNA, which is short-lived and is processed into 5.8 S, 18 S and 28S *r*RNAs. The systematic transcription of rows of genes simultaneously, gives to *r*DNA the appearance of a *christmas tree.* Nucleolus is thus actively involved in the synthesis of different types of ribosomal RNAs.

The assembly of ribosomes takes place on the surface of the nucleolus, from which, the ribosomal RNAs are formed within the nucleolus and ribosomal proteins are synthesized in the cytoplasm. From the cytoplasm, the ribosomal proteins are transported to the surface of the nucleolus where they are assembled with the *r*RNAs to form the ribosomes. These ribosomes are of 80 S type. At the time of cell division, the necleolus is withdrawn within the nucleolar organiser of the chromosome.

(*iv*) **Chromatin network.** This forms the skeleton of the nucleus and is so organised as to give a reticular appearance. Chromatin threads are the sites of main genetic material which controls all activities of the cell, metabolism as well as heredity. During cell division, the chromatids become tightly coiled, get enclosed in a definite proteinaceous matrix and are identified as chromosomes.

Chemically on dry weight basis, a nucleus has 70% proteins, 10–14% lipids, 5–10% DNA, 3–5% phospholipids and a chromatin consisting of DNA, some RNAs, some *RNA polymerases* and 3–5 or even more types of proteins (histones).

CHROMOSOMES

Strasburger (1875) is credited with the discovery of these thread-like structures which appeared during cell division. These structures called chromosomes (Greek word: *chroma* = colour; *soma*=body) became the most significant component of the cell, present in a highly organised fashion within the nucleus and specific in their number, size and shape.

Morphology of Chromosomes

The morphological aspects of a chromosome are studied during metaphase or anaphase. The number of chromosomes in a nucleus varies to a great extent and is a *species-specific trait.* In *Haplopappus gracilis,* a diploid nucleus contains only 4 chromosomes, while in *Ophioglossum regalis* (a pteridophyte) there are 1262 chromosomes in a diploid nucleus. Haploid set of chromosomes which is inherited is called **genome** and the whole collection of chromosome in a nucleus is referred to as chromosome complement. The genome in *Pisum sativum* is 7, *Allium cepa* is 8 etc. The size of chromosome shows a variation from 0.25 μm in fungi to 3.0 μm in some plants.

The shape of the chromosome is decided by the position of the centromere. Accordingly these may be of four types:

(*i*) *Telocentric*–The centromere is at the tip of the chromosome.

(*ii*) *Acrocentric*–The centromere is sub-terminal and chromosomes appear rod-like, having one small arm and the other very long.

(*iii*) *Sub-metacentric*–The centromere is close to the centre and the chromosome has unequal arms resembling a J-shape.

(*iv*) *Metacentric*–Centromere is situated at the centre of the middle part of the chromosome and has two equal arms. It appears V-shaped.

Structure

Chromosome is the most wonderful gift of nature. Structurally, they appear as a rod-shaped structure, bounded by a proteinaceous pellicle which encloses a jelly-like substance called matrix. The presence of matrix has been clearly shown in *Luzula campestris* (woodrush).

During metaphase, a chromosome is seen to consist of two symmetrical structures called chromatids, which become intertwined in the matrix. These chromatids are attached to each other by the centromere. During prophase and sometimes during metaphase, the chromosomal material becomes visible as very thin filaments called *chromonemata.* Several chromonemata coiled together and enclosed in a separate common matrix form a chromatid. The chromonema may be composed of 2, 4 or more fibrils which are coiled with each other. If the coiling is easily separable, it is termed as paranemic coiling and if closely intertwined and inseparable, it is termed as plectonemic coiling. The chromonemata of one chromosome are identical in nature to the chromonemata of other chromosomes in the same cell.

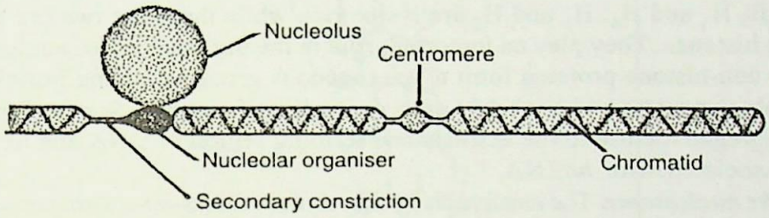

Fig. 1.22. Schematic figure of a chromosome.

The group of chromonemata at places show superimposed coiling, forming a dark band-like structure called *chromomere,* whereas the regions in between two chromomeres are designated as *interchromomeres.* The chromomeres were earlier believed to be the sites of genes, but these dark band structures found on chromosomes are now called heterochromatin segments and are the sites of genetically inactive genes. Euchromatin segments are light in colour and are genetically active.

The chromosome is not uniform throughout, but has a constriction called *centromere.* These have a basic structure consisting of a dense, dark-staining region called spherule or kinosome surrounded by inter-chromomeral fibrillae. Centromere has two important functions:

(*i*) It holds the two sister chromatids together until the end of the metaphase.

(*ii*) It is the site for the attachment of spindle fibres in order to transport the sister chromatids to opposite poles. This is mediated by the kinetochore. Chromosomes are usually monocentric (one centromere) but some are dicentric (two centromeres) or polycentric (many centromeres).

The chromosomes in addition to primary constriction (centromere) may sometimes possess secondary constriction at any point. It is associated with the nucleolus and may take part in the reorganisation of the nucleolus at the end of cell division, as such it may be called nucleolar-organising region. The part of the chromosome,

which is present beyond the secondary constriction is called *satellite body,* and the chromosome, bearing satellite is termed as *SAT-chromosome.*

Ultrastructure of Chromosomes

In view of recent studies related to the ultrastructure of chromosomes, some important points are considered here:

1. ***Strandedness of a chromosome.*** The eukaryotic cell contains an enormous amount of DNA which remains greatly compressed and packaged inside a chromosome. A question is raised at this stage. Is there one DNA duplex in a chromatid (unineme or single strandedness) or more than one (multineme or multistrandedness)? This question remains much debated. However, it is now generally accepted that the chromosome is unineme, containing a single DNA duplex per chromatid.

2. ***Chromosomal proteins.*** Different types of proteins found in a chromosome are divided into two broad categories, the *histones* (or basic proteins) and the *hertones* or *non-histones* (or less basic proteins). Histones represent the largest proportion of chromosomal proteins and usually exceed DNA by weight.

All histones are rich in basic amino acids, but differ in relative proportions of lysine and arginine. Histones are classified into five types designated as H_1, H_2A, H_2B, H_3 and H_4. H_1 and H_2 are lysine rich while the other two are arginine they rich histones. They play an important role in the organisation of nucleosomes.

The non-histone proteins form a heterogenous group including proteins with structural, enzymatic and probably gene controlling functions. Some of these are found aggregated close to the actively transcribing region of DNA and have been found associated with *hn*RNA.

3. ***The nucleosome.*** The inactive chromatin shows a *beads-on-a-string* appearance. Olins and Olins (1974) called these knob-like structures, the **nu-bodies.** The term **nucleosome** was given to these beads by Oudet, Goss-Bellard and Chambon (1975). Nucleosomes are present in all the eukaryotic cells, both in plants and animals.

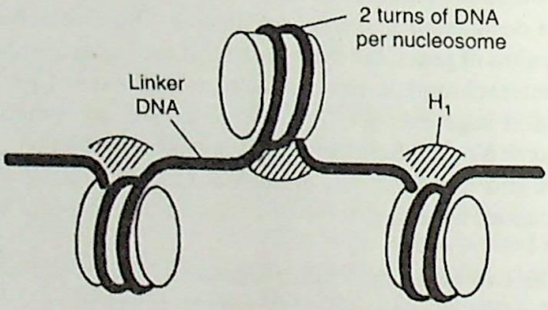

Fig. 1.23. A part of chromatin (highly enlarged) showing that the nucleosome is flat and that each histone octomer has two turns of DNA sealed off by histone H_1.

The bead and the connecting string form one repeat unit. The bead is called **core particle** or **nucleosome** and the connecting string is called **linker region** or **spacer region** or internucleosomal region. Structurally, the repeat unit consists of 200 base pairs (bp) of DNA and 9 molecules of 5 types of histone proteins.

The core particle or nucleosome contains 140 bp of DNA wound in two complete (or 1.75 turns) superhelical turns around eight molecules (octomer unit) of histone proteins, two each of H_2A, H_2B,'H_3 and H_4. About 60 bp of DNA are found in the linker or spacer region with which histone H_1 remains associated. The nucleosome should not be considered as a gene as it is much smaller than that.

4. ***The supra-nucleosomal structure*** (or ***Solenoid model***). The supra-nucleosomal structure explains how the nucleosomes are packed into the 200–300 Å thick nucleofilament of chromatin. Finch and Klug (1976) found a close packing of nucleosomes to produce a nucleofilament, a fibre 100 Å in dia. The nucleofilament is further coiled up to form the solenoid with a dia. of 300–350 Å. There are about six nucleosome per turn of the solenoid coils. Kornberg and Klug (1981) suggested that H_1 leads to folding of nucleofilament to form the solenoid.

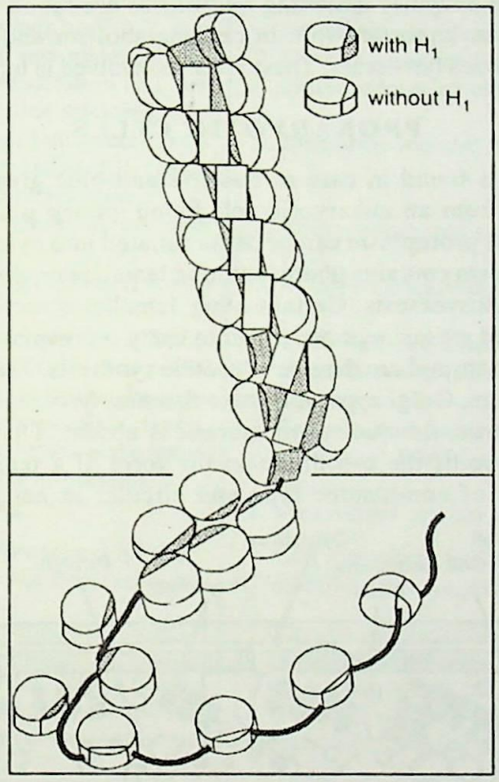

Fig. 1.24. Solenoid superstructure, lower portion showing open zigzag of nucleosomes (after removing H_1).

Chemical Composition of Chromosomes

The chief constituents of a chromosome are DNA, RNA and proteins. Proteins are both histone and non-histone types. Calcium is also present. Non-histone proteins are sometimes referred to as hertones.

VACUOLES

Vacuoles, starch grains, aleurone grains, oil droplets etc., are the non-living cell inclusions. Vacuoles are not visible in young stage but as the cells grow in size and enlarge they start making their appearance like small droplets which go on coalescing with each other to form a bigger vacuole at maturity. At maturity the size of vacuoles may enlarge to such an extent that cytoplasm is left only in the form of cytoplasmic strands enclosing the nucleus. Surrounded by the tonoplast, a unit lipopoteinaceous membrane, vacuoles contain cell sap with atmospheric gases, mineral salts, sugars, organic acids (such as acetic acid, malic acid and tartaric acid) and at times anthocyanin pigments. The various colours of petals are due to the presence of various dissolved anthocyanin pigments present in vacuoles. Some solid bodies of aleurone grains and soluble proteins are also found in vacuoles.

Several types of enzymes including *hydrolases* are found in vacuoles (Matile, 1978). These play an important role in cell metabolism and may act as storage compartments and also as lysosomes. These are also involved in turgor and detoxication.

PROKARYOTIC CELLS

A prokaryotic cell is found in case of bacteria and blue green algae and differs in certain respects from an eukaryotic cell found among plants and animals. In prokaryotic cells, the protoplasm can be differentiated into cytoplasm and incipient nucleus. The cytoplasm contains photosynthetic lamellae or chromatophores which are the sites of photosynthesis. Certain other lamellar structures or infolding of cell membrane called *mesosomes* are found to carry on respiration. The ribosomes lie free in the cytoplasm and are the site of protein synthesis. Plastids, mitochondria, endoplasmic reticulum, Golgi apparatus, peroxisomes, lysosomes etc. are not found. The nucleus is not true, *i.e.* nuclear membrane is absent. The chromatin material lies free in the centre of the cytoplasm in the form of a tangled mass. DNA of prokaryotic cells is of non-histone type and circular in nature.

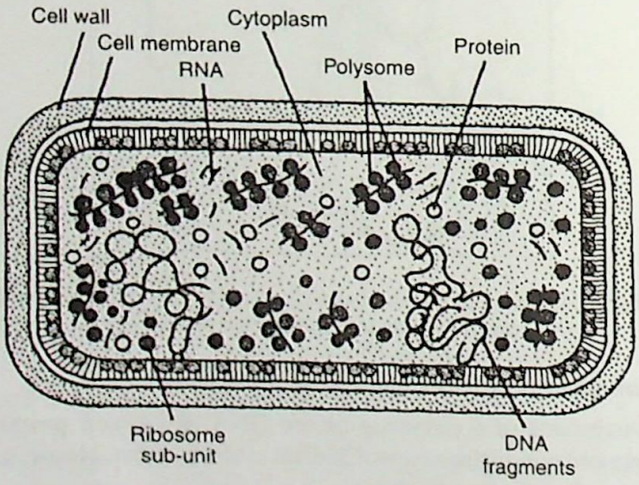

Fig. 1.25. A typical prokaryotic cell (*Escherichia coli*) showing different structures.

Mesosomes (discovered by Fitz-James, 1960) are characteristic structure of bacterial cell. These have also been called plasmalemmasome. The term mesosome refers to any of the intracytoplasmic membranous structure which appears to originate from the cell membrane by the invagination and pinching off process. The mesosomes participate in energy production (respiration), DNA replication, nucleoid separation, cell division, photosynthesis, nitrogen fixation, endosporulation etc.

The prokaryotic cell differs from a eukaryotic cell by different features as summarised in Table 1.4.

Table 1.4. Differences Between Prokaryotic and Eukaryotic Cells.

Prokaryotic cell	*Eukaryotic cell*
1. Nucleus is incipient type. It lacks nuclear membrane, nucleolus and chromatin reticulum (chromosome).	1. It has a true nucleus in which nuclear membrane, nucleolus and chromatin reticulum are present.
2. DNA is circular and non-histone type, *i.e.* it lacks protein association and lies in a tangled mass called nucleoid.	2. DNA is associated with protein to form chromosomes or chromatids.
3. All membrane-bounded structures such as chloroplast, mitochondria, ER, Golgi complex, vacuoles etc. are absent.	3. Membrane bounded structures are present.
4. Cell wall contains aminosugars and muramic acids.	4. These substances are absent in the cell wall.
5. Cytoplasmic streaming (cyclosis) is not observed.	5. It can be observed.
6. In autotrophic forms, photosynthetic pigments are found associated with lamellae but not enclosed by membranes.	6. Lamellae are enclosed in two unit membrane envelope and called chloroplast.
7. Flagella do not show 9+2 fibril arrangement. These are hollow and tubular and made up of flagellin proteins.	7. Flagella comprise of 2 central and 9 peripheral fibrils, made up of tubulin proteins.
8. Mesosomes are found.	8. Mesosomes are not found.
9. Cell wall and cell membrane have intricate contact and these do not fully separate during plasmolysis.	9. Cell membrane lies separate and shows complete shrinkage during plasmolysis.
10. Endomembranes are absent.	10. Endomembranes are present.
11. Endocytosis and exocytosis are not found.	11. Both phenomena are found.
12. Only 70 S type of ribosomes are found.	12. Both 70 S and 80 S ribosomes are found.
13. Microtubules and nucleosomes are not found.	13. Microtubules and nucleosomes are found.
14. RNA plays a major role in the condensation of DNA forming genophore.	14. Proteins (histones and hertones) play major a role in the condensation of DNA forming chromatid or chromosomes.
15. A single replication site is formed during replication of DNA.	15. Several replication sites are formed during DNA replication.
16. During transcription, a single type of RNA polymerase is found.	16. During transcription, three types of RNA polymerases are found.
17. *nif*-genes are found in some prokaryotes.	17. These are not found in eukaryotes.

MESOKARYOTIC CELL

Dodge (1964) used the term mesokaryotic cell to refer to the nuclear status of dinoflagellates (a group of algae). It is characterised by the absence of deoxyribonucleohistone (as in prokaryotic cells).

Nucleus is, however, definite but possesses many unusual properties including persistence of chromosomes in a condensed configuration during interphase and absence of centromeres or a spindle. The nucleus shows a typical type of division called *dinomitosis*. The nuclear membrane and nucleolus are persistent throughout the division. Stages like metaphase and anaphase are not found.

Table 1.5. Some Cell Organelles and Their Functions.

Structure	*Function*
Nucleus (5-30 µm)	
(*i*) Chromosomes	Ultimate control of cell, carrier of genes.
(*ii*) Nucleolus	Ribosomal RNA synthesis and controls cell division.
(*iii*) Nuclear membrane	Regulates the entrance and exit to and fro from cytoplams.
Cytoplasm	
(*i*) Endoplasmic reticulum (200 Å)	Provides attachment surface for protein synthesis; acts as secretion channel and maintains connection between cell parts and cell to cell.
(*ii*) Mitochondria (0.5–2.0. µm)	Site of Krebs cycle and electron transport chain.
(*iii*) Ribosomes (250 Å)	Site of protein synthesis.
(*iv*) Golgi Complex	Site of synthesis of lytic enzymes and supports cell wall formation.
(*v*) Lysosomes (0.2–2 µm)	Site of hydrolytic enzymes, digestion, autolysis.
(*vi*) Spherosomes (0.7 µm)	Site of hydrolytic enzymes.
(*vii*) Chloroplast (2–6 µm)	Site of photosynthesis.
(*viii*) Peroxisomes (1 µm)	Concerned with photorespiration.
(*ix*) Glyoxysomes (1 µm)	Concerned with glyoxylate metabolism.
(*x*) Lomasomes	Cell wall synthesis.
Surface	
(*i*) Plasma membrane (75 Å)	Traffic control to-and-fro from cell.
(*ii*) Cell wall	Provides support, protection and definite cell shape.
(*iii*) Cuticle	Support and protection.

STUDY QUESTIONS

1. Define cell and illustrate briefly that the cell is the structural and functional unit.
2. Justify the statements: "The use of electron microscope has helped in a better understanding of the structures of cell."
3. Describe the nature and composition of plastids.
4. Justify the statement "Cell is the chemical and biochemical basis of life."
5. Write notes on:
   (*i*) Cell Wall
   (*ii*) Ultrastructure of cell membrane
   (*iii*) Plastids
   (*iv*) Ultrastructure of chromosome

6. Give the structure and function of:
   (*i*) Ribosomes
   (*ii*) Nucleolus
   (*iii*) Mitochondria
7. Write a note on differences between eukaryotic and prokaryotic cells.
8. Write short notes on:
   (*i*) Nucleosome
   (*ii*) Solenoid model
   (*iii*) Golgi bodies
   (*iv*) Peroxisomes
   (*v*) Lysosomes
9. Briefly describe–
   (*i*) Distribution of enzymes is mitochondria.
   (*ii*) Light harvesting complex of chloroplast
   (*iii*) GERL
   (*iv*) Differences between 70 S and 80 S types of ribosomes
   (*v*) Microsomes
   (*vi*) Microtubules
   (*vii*) Ultrastructure of flagellum
   (*viii*) Endoplasmic reticulum
   (*ix*) Glyoxysomes and spherosomes
   (*x*) Origin of chloroplast and mitochondria
   (*xi*) Functions of mitochondria
   (*xii*) Molecular organisation of thylakoids
   (*xiii*) Protoplasm
   (*xiv*) Chemical changes in plant cell wall