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Abstract

A cell is the fundamental unit of life since no living organism can survive without it. Also, the cell is both a structural and a functional unit of a living system. On the basis of complexity and organization of life, cells can be classified into two types—prokaryotic cell and eukaryotic cell. Prokaryotes are unicellular organism that lack distinct nucleus and other membrane-bound organelles. The average size of prokaryotes is 2.0–2.6 μm . Eukaryotic cells have a nucleus enclosed within a nuclear envelope and different membrane-bound organelles. In a cell cyto-

plasm, a semisolid matrix substance is enclosed by cell wall and cell membrane. The major cell organelles are mitochondria, Golgi apparatus, endoplasmic reticulum, ribosome, lysosome, etc. In eukaryotes, the nucleus is a specialized double membrane-bound protoplasmic entity that houses all of the genetic information needed to control cellular metabolism and pass on to future generations. The cytoskeleton is the structural framework of eukaryotic cells that keeps the cell and its appendages in shape. Genetic information flows from ‘DNA to mRNA to protein’ within cell.

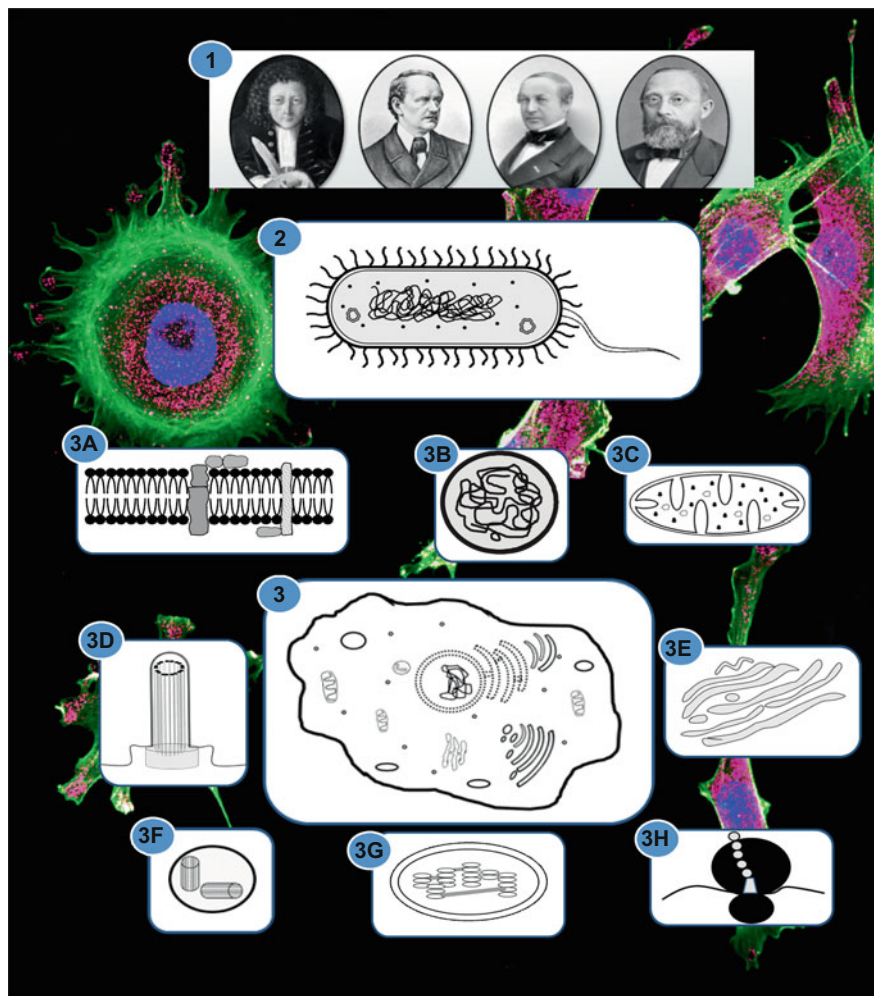
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Graphical Abstract



Description of the graphic: Pioneering scientists—Robert Hooke, Matthias Schleiden, Theodor Schwann, and Rudolph Virchow (from left to right) (1) discovered cell. A typical prokaryotic cell (2) and a typical eukaryotic cell with cell organelles (3) includes Biomembrane structure (3A) Nucleus (3B) Mitochondria (3C) Cytoskeletal structure (3D) Golgi Apparatus (3E) Centriole (3F) Chloroplast (3G) and Ribosome (3H)

Keywords

Prokaryotes · Eukaryotes · Cytoplasm · Nucleus · Cytoskeleton

The cell concept... is the axis around which the whole of modern science of life revolves—Paul Ehrlich in Nobel Lecture on 11 Dec 1908

Learning Objectives

- Development of ideas about basic structure and components of prokaryotic and eukaryotic cells.
- Structure of cell wall, cell membrane, and biomembrane.
- Cellular organelles—their structure and functions—nucleus, endoplasmic reticulum, Golgi apparatus, mitochondria, plastids, ribosomes, vacuoles, lysosomes.
- Structural organization of cytoskeleton.
- Flow of molecular-genetic information within cell.

2.1 Cell: The Smallest Unit of Life with Independent Existence

Life begins as a cellular unit. A cell is a fundamental unit of life since no living entity can exist without a cellular structure, and a cell is a unit of both structure and function. Numerous unicellular organisms are present in the universe, where single cell is sufficient to perform the fundamental processes of life, for example, bacteria, Protista, protozoa, and yeast. A multicellular organism like a higher animal or

plant has billions of cells. For example, an average man of 70 kg weight and 1.72 m height with a body area of 1.85 m² has 37.2 trillion cells of about 200 types. Cells are clubbed to form tissues, tissues to organs, and organs to organ systems.

Cells are also the functional units of life. As Francois Jacob quipped (1971), ‘the dream of every cell is to become two cells’ a new cell is formed by the division of an existing cell. A totipotent single cell has unique capability to develop into the whole organism.

2.2 Notable Events in the Discovery of Cell

Year	Event
• 1590	Zacharias Janssen built the first microscope.
• 1661	Marcello Malpighi observed cells and named ‘sacculi’ and ‘utricles’.
• 1665	Robert Hooke improved the design of microscope. He observed honeycomb like compartments in a piece of cork of Spanish Oak. In his famous book ‘Micrographia’, he named these compartments as <i>cellulae</i> (Latin ‘cella’ means ‘hollow space’).
• 1671	Antonie van Leeuwenhoek first observed, described, and depicted the picture of free-living cell.
• 1831	Robert Brown discovered the nucleus in the cells of orchid root.
• 1835	Félix Dujardin discovered protoplasm in <i>Foraminifera</i> and named it ‘sarcode’. Later, J.E. Purkinje termed it as ‘protoplasm’.
• 1839	‘Cell theory’ proposed by Matthias Schleiden and Theodor Schwann.

Know More.

Cell Theory

Cell theory is one of the fundamental ideas of biology. German scientists *Theodor Schwann*, *Matthias Schleiden*, and *Rudolph Virchow* formulated the theory.

Tenets to the Cell Theory: Schwann and Schleiden first stated that

- The cell is the fundamental unit of structure and function in living things.
- All organisms are made up of one or more cells.

Later, Virchow stated the third tenet

- ‘*Omnis cellula e cellula*’ i.e. ‘All cells arise from pre-existing cells’.

Modern Cell Theory

- Energy flow occurs within cells.
- Heredity information (DNA) is passed on from cell to cell.
- All cells have the same basic chemical composition.

2.3 Types of Cells

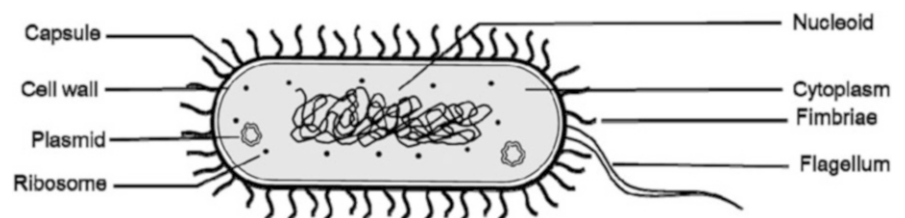
Based on the complexity and organization of DNA, cells can be categorized into two types—prokaryotic cells and eukaryotic cells.

2.3.1 Prokaryotic Cells

Prokaryotes are unicellular organisms that lack a distinct nucleus and other membrane-bound organelles (Fig. 2.1). The average size of prokaryotes is 2.0–2.6 μm. Based on different molecular determinants prokaryotes are divided into two domains: Bacteria (formerly Eubacteria) and Archaea (formerly Archaeobacteria). The different components of prokaryotic cells are described below:

- **Nuclear material:** Naked, coiled DNA lies in the cytoplasm. This DNA is also known as gonophore or prochromosome. In some prokaryotes, extrachromosomal DNA is found as small circular plasmids.
- **Vacuoles:** Gas vacuoles are present in prokaryotes.

Fig. 2.1 Structure of a prokaryotic cell



- **Ribosomes:** 70S ribosomes comprising of 50S and 30S subunits are present in prokaryotes.
- **Photosynthetic thylakoids:** Thylakoids lie freely in the cytoplasm in blue-green algae and some bacteria.
- **Cell wall:** Bacteria and cyanobacteria are encased by a cell wall.
- **Capsule:** In addition to the cell wall, some bacteria have an outer protective layer. It aids in the retention of hydration, protecting cells from phagocytosis, and cell attachment.
- **Flagella and fimbriae:** In some bacteria, flagella and fimbriae are present. Flagella help in bacterial motility whereas fimbriae facilitate conjugation and attachment.
- **Middle lamella**—Middle lamella is the common layer between two adjacent cells. It is made up of calcium and magnesium pectates. This is the initial layer that is laid down during cytokinesis process.
- **Primary wall**—The extensible, thin wall (0.1–3 μm) present at the inner side of the middle lamella is primary wall. A loose network of microfibrils embedded in an amorphous gel-like matrix or ground substance makes up the primary wall. Microfibrils are generally made up of cellulose in plants. This cellulose is synthesized at cell membrane by particle rosette harbouring cellulose synthetase enzyme. The main component of fungal cell wall is repeating unit of β , 1–4 acetyl glucosamine or fungal cellulose. The wall grows by intussusception or deposition of materials inside.
- **Secondary wall**—The secondary wall is formed by gradual accumulation of materials at the inner side of primary wall on the existing structure. It is thicker (3–10 μm) than the primary wall and composed of minimum of three layers. The constituents of the secondary wall are almost similar to the primary wall. Compared to primary wall cellulose content is higher and cellulose microfibrils are longer and denser. The matrix in which cellulose microfibrils are embedded contains pectin and hemicellulose. Materials like suberin, lignin, silica, and cutin are deposited in the secondary wall.

2.3.2 Eukaryotic Cells

Eukaryotic cells have a nucleus enclosed within a nuclear envelope and different membrane-bound organelles (Fig. 2.2).

Eukaryotes can reproduce asexually through mitosis and sexually through meiosis and gamete fusion. The various components have been detailed here for better comprehension of the structure and function of eukaryotic cells.

2.3.2.1 Cell Wall

The cell wall is an outer structural layer surrounding the plant cells, fungi, and a few protists providing necessary support to the cell. Its thickness ranges from 0.1 to 10 μm . Cell wall is metabolically active and can grow.

2.3.2.1.1 Chemical Composition

The principal components of the plant cell wall are cellulose, hemicellulose, pectin, and protein. In algal cell walls galactans, mannans, and calcium carbonate are also present.

2.3.2.1.2 Structure

Structurally the cell wall comprises three parts—middle lamella, primary wall, and secondary wall.

Apart from this basic structure cell wall may possess some specialized structure like *plasmodesmata* and *pits*. *Plasmodesmata* are cytoplasmic bridges in the shape of minute pores that connect adjoining plant cells to form a symplast or continuous protoplasm (Fig. 2.3).

Plasmodesmata (diameter 40–50 nm) are encircled by plasma membrane. An endomembrane-derived structure connecting Endoplasmic Reticula (ER) of two adjacent cells (*desmotubule*) is present within plasmodesmata. Plasmodesmata regulate transport of various small molecules between two adjacent cells. *Pits* are unthickened areas present on secondary walls of plant cell. These submicroscopic pores help in rapid translocation of essential molecules between two neighbouring cells.

Fig. 2.2 Structure of a eukaryotic

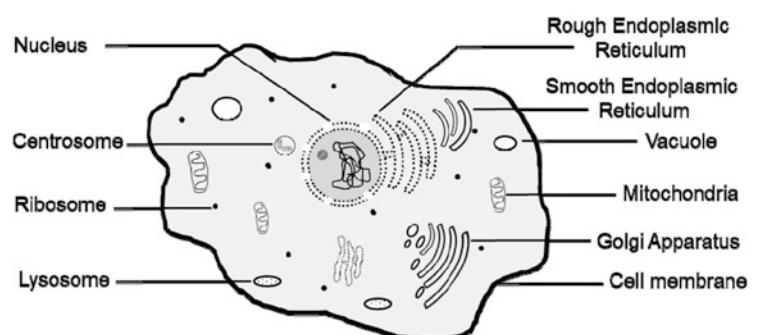
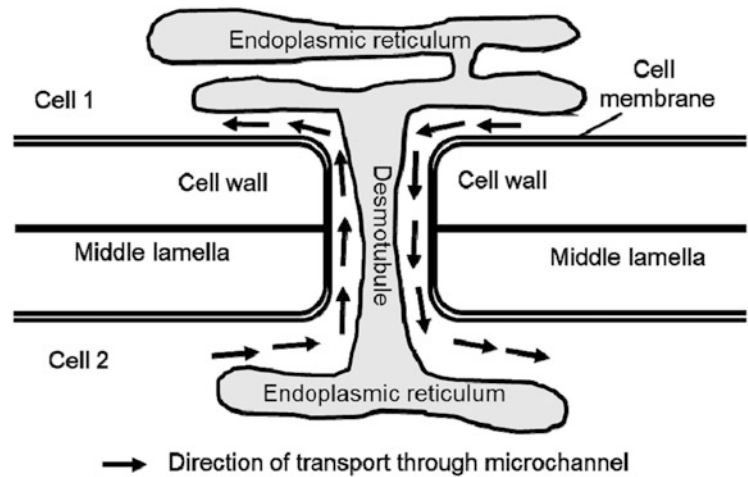


Fig. 2.3 Structure of plasmodesmata



2.3.2.1.3 Functions

(1) Cell wall provides structural firmness and shape of cell. (2) It withstands osmotic pressure and prevents rupture of cells. (3) It protects cellular protoplasm from mechanical damage and external pathogens. (4) Cell wall of sieve tubes and vessels ensure long distance transport. (5) Cell wall stores food in the form of hemicellulose in some seeds.

2.3.2.2 Cell Membrane

Cell membranes or biomembranes are dynamic, quasifluid, thin (50–100 Å) structure surrounding the cytoplasm and several cell organelles like nucleus, mitochondria, endoplasmic reticulum, Golgi bodies, lysosome, ribosome, vacuoles, etc. Biomembranes are selectively permeable for various solutes.

2.3.2.2.1 Chemical Composition

Water—20%, Carbohydrates—1–5%, Lipid—20–79%, Proteins—20–70%.

Carbohydrates—Different types of branched and unbranched oligosaccharides like hexose, fucose, hexosamine, sialic acid, etc. Proteins—globular and fibrous proteins. Lipids—phosphoglycerides or phospholipids.

2.3.2.2.2 Structure

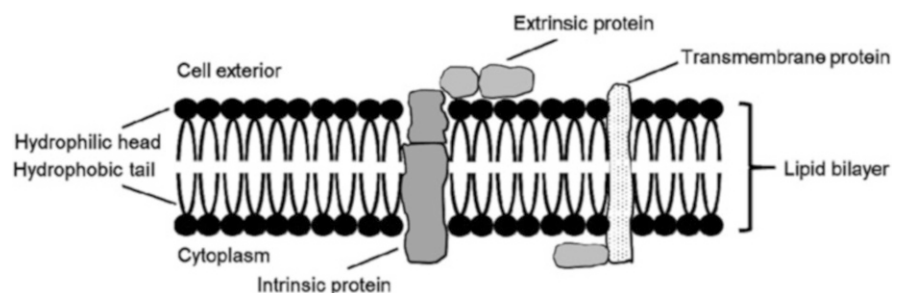
Several models have been proposed to explain the molecular structure of cell membrane. According to the earliest lamellar

models proposed by J. Danielli and H. Davson (1935), four-layered biomembrane comprises two phospholipid layers covered on either side by two layers of proteins. Later, Robertson's model proposed that outer and inner protein layers differ in distribution of protein molecules in 1959. The outer protein layer is enriched in mucoid protein whereas inner one is rich in nonmucoid proteins. Robertson's pioneering work on electron microscopic structure of erythrocyte membrane also theorized the unit membrane concept which stated that all cytoplasmic membranes are three-layered sandwich structure of protein-phospholipid-protein. Robertson called this trilaminar membrane. In the lamellar models proposed by both the groups, biomembrane has been proposed as a stable structure. However, the *fluid-mosaic model* of Singer and Nicolson (1972), the most accepted model of biomembrane, depicted it as dynamic structure with the ability to fuse or separate, expand, or contract during diverse cellular processes (Fig. 2.4).

2.3.2.2.2.1 Characteristics of Fluid-Mosaic Model

(1) Mosaicism—Lipid molecules are present in viscous bilayer. Intrinsic and extrinsic protein molecules are present inside and outside of the lipid bilayer, respectively. *Intrinsic or integral* protein molecules penetrate the lipid bilayer at various depths and form hydrophobic interactions with lipid molecules. Several integral proteins span the complete lipid

Fig. 2.4 Fluid-mosaic model of biomembrane or cell membrane



bilayer. Those are called *transmembrane* proteins. *Extrinsic* or *peripheral* proteins are found superficial to the membrane's two surfaces, covalently bound to the phospholipid head or noncovalently attached to transmembrane proteins. (2) Fluidity—Because the lipid bilayer is quasifluid in nature, membrane proteins can move laterally, giving the membrane flexibility and dynamism. Electron spin resonance, atomic force microscopy-based force spectroscopy, fluorescence, and deuterium nuclear magnetic resonance spectroscopy can all be used to determine membrane fluidity. Composition of the membrane and temperature are two most important determinants that control the fluidity of membrane. Similarly, because unsaturated fatty acids contain kinked hydrocarbon tails, lipid molecules with unsaturated fatty acids are more difficult to pack together, increasing fluidity. In animal cell membrane, cholesterol functions as a bidirectional regulator of membrane fluidity. At increased temperatures, it stabilizes the membrane and elevates its melting point, whereas at low temperatures it intercalates between the phospholipids and prevents their aggregation and stiffening, thereby increases fluidity. (3) Asymmetry—Biomembranes are asymmetric, i.e. the two sides of the biomembranes differ in the amount and types of constituent molecules like lipid, protein, and carbohydrate moieties. As for erythrocyte membrane, lecithin is present on exterior side and cephalin is rich in cytoplasmic side. Most of the membrane proteins are also abundant on inner surface. On the contrary, oligosaccharides are mostly present in outer surface and absent in inner surface of biomembrane.

2.3.2.2.3 Function

Biomembrane or cell membrane has diverse types of functions. (1) Cell membrane protects cell from mechanical stress. (2) It facilitates intracellular transport of water and different solute molecules. (3) Biomembrane structure maintains the identity and internal milieu of each cell organelle. (4) Cell membrane has receptors for different biologically significant molecules like antigens, hormones, etc. (5) Cell membrane harbours crucial enzymes like ATPase, esterase, etc. (6) In neuronal cells, cell membrane participates in neurotransmission.

2.3.2.3 Cytoplasm

Cytoplasm is a gelatinous, semi-fluid mass inside the cell containing cytosolic matrix, organelles and inclusion bodies excluding the nucleus. The components are cytoplasmic matrix, cell organelles, and cell inclusions.

2.3.2.3.1 Cytoplasmic Matrix (Cytosol or Hyaloplasm)

Cytosol is the main component of cytoplasm making 70% of the cytoplasm volume. It comprises water, cytoskeleton filaments, and dissolved molecules. Cytosol is a colloidal solution of different chemical molecules in water. Proteins

are mostly present as colloidal particle, whereas lipids remain as emulsion. Outer part of cytosol is called the *cell cortex* or the *ectoplasm* whereas the concentrated inner area is called the *endoplasm*. Cytosol often exists in two states, *sol* and *gel*.

2.3.2.3.1.1 Function

(1) Cytosol functions as medium for exchange of materials between cell organelles. (2) Cellular metabolism takes place in cytosol. (3) Biosynthesis of carbohydrates, lipids, proteins, and nucleotides takes place in the cytosol. (4) Cytoplasmic streaming of matrix helps in even distribution of various essential materials inside cell.

2.3.2.4 Cell Organelles

Cell organelles are morphologically distinct subcellular structures with diverse chemical compositions and discrete functions. A cell contains diverse cell organelles like mitochondria, plastids, Golgi bodies, endoplasmic reticulum, peroxisomes, ribosomes, lysosomes, etc.

2.3.2.4.1 Mitochondria

Mitochondria are eukaryotic cell organelles that play a critical role in the generation of metabolic energy. Mitochondria are also called the *power houses* of the cell because they are the main source of energy released by oxidative phosphorylation and Krebs's cycle of aerobic respiration. Mitochondria are cylindrical in shape (length of 1.0–4.1 μm and diameter of 0.2–1.0 μm).

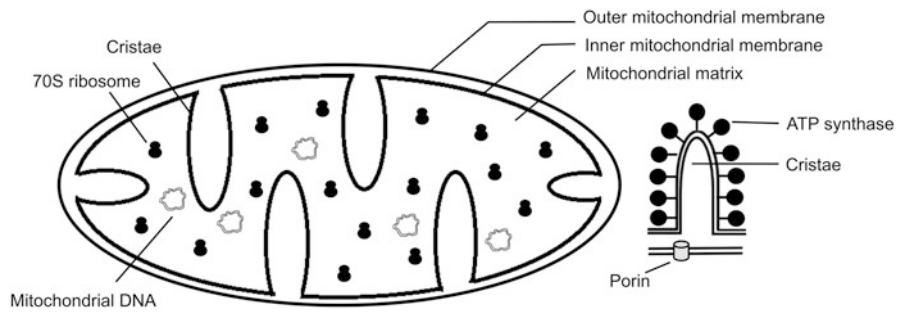
2.3.2.4.1.1 Chemical Composition

Proteins—60–70%, Lipids—25–35%, RNA—5–7%, DNA. Small quantity of trace minerals

2.3.2.4.1.2 Ultrastructure

A mitochondrion contains two membranes (60–75 \AA thickness) and two chambers, outer and inner (Fig. 2.5).

- *Outer chamber*: The outer chamber or peri-mitochondrial space is the space (60–100 \AA) between the outer and inner membranes of the mitochondrial envelope. The chamber contains different enzymes.
- *Inner chamber*: Inner chamber is filled with a semi-fluid matrix that contains ribosomes, protein particles, RNA, DNA, and enzymes of amino acid synthesis, fatty acid metabolism, Krebs's cycle.
- Mitochondria have naked, circular, or linear DNA. Mitochondrial ribosomes resemble prokaryotic ribosomes and are 55S or 70S in nature.
- *Outer membrane*: Mitochondria is surrounded by a smooth outer membrane. Several metabolites (less than 1000 Da) can make passage within mitochondria due to the presence of *porin* channels and other small pores in the outer membrane.

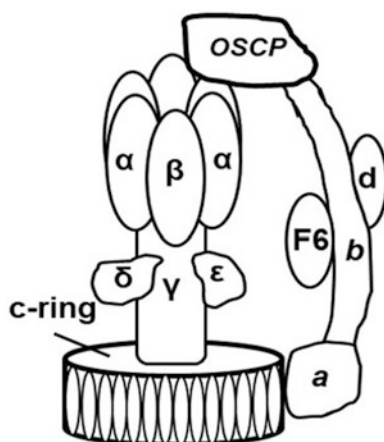
Fig. 2.5 Structure of mitochondria

- **Inner membrane:** Unlike outer membrane inner membrane is permeable to fewer metabolites. Inner membrane is rich in phospholipid molecule *cardiolipin* and many proteins. The inner membrane is folded variously to form finger-like projections called *cristae*. Presence of cristae provides adequate surface area for mitochondrial reactions to occur.

Cristae are studded with variety of proteins, including *ATP synthase* and different *cytochromes*. Inner membrane as well as cristae possess small tennis-racket like *ATP synthase dimer* (earlier known as *elementary particles* or *oxisomes*). *ATP synthase* in eukaryotes is F-type and consists of two major subunits, F_O and F_1 . The F_1 (Fraction 1) part of *ATP synthase* has three copies of each of subunits α and β , one each of subunits γ , δ , and ϵ . The γ , δ , and ϵ subunits constitute the central stalk or the rotor shaft (Fig. 2.6). A hexameric ring with a central cavity is formed by an alternate arrangement of 3α and 3β subunits. F_O subunit consists of a subunit c-ring and one copy each of subunits a, b, d, F6, and the oligomycin sensitivity-conferring protein (OSCP).

2.3.2.4.1.3 Functions

(1) Primary function of mitochondria is to produce energy through the process of oxidative phosphorylation. (2) It regulates the metabolic activity of the cell. (3) It plays an

**Fig. 2.6** ATP synthase subunits

important role in apoptosis or programmed cell death. (4) It also stimulates cell multiplication and cell growth. (5) Mitochondria detoxify ammonia in the liver cells.

2.3.2.4.2 Plastids

Plastids are a type of semi-autonomous organelle with DNA and a membrane that stores or synthesizes a wide range of biological chemicals. Plastids are present only in plant cells (except few protists like *Euglena*, diatoms). A. F. W. Schimper was the first to name plastids and give them a precise definition. Plastids differentiate from proplastids and are classified into three categories based on their colour: *leucoplasts*, *chromoplasts*, and *chloroplasts*.

- **Leucoplasts**—These are colourless plastids which generally occur near the nucleus of the cells. Based upon the content of leucoplasts, these plastids may be of different types. Elaioplasts (found in tube rose) are colourless plastids that store lipid. Amyloplasts (found in rice, wheat) contain starch within it and proteoplasts (found in maize) have protein inside the plastids.
- **Chromoplasts**—These are found in different flowering plants and contain coloured pigments.
- **Chloroplasts**—These are greenish plastids which possess photosynthetic pigments, chlorophylls.

2.3.2.4.2.1 Composition

Protein—50–60%, lipids—25–30%, chlorophyll—5–10%, carotenoids—1–2%, DNA—0.5%, RNA—2–3%, Trace minerals and vitamins.

2.3.2.4.2.2 Structure

Chloroplasts are made up of three parts: *envelope*, *matrix*, and *thylakoids*. Chloroplasts have two membranes covering them. Each membrane is 100 Å thick and divided by a gap called inter-membrane space. Matrix, often known as *stroma*, is a protein-rich semi-fluid compound. The stroma contains DNA, RNA, 70S ribosome, and many enzymes. Thylakoids are membrane-lined flattened sacs that are found in the stroma. Two to hundred thylakoids are piled to create *grana* in higher plants. In chloroplasts, there are about 40–60 grana. Membrane of thylakoids harbour photosynthetic pigments

and coupling factors. Photosynthetic pigments are found in photosystems in a group. Plants have two types of photosystems: photosystem I (PS-I) and photosystem II (PS-II). PS-II is found in appressed part of grana, whereas PS-I is located within non-appressed stroma lamellae.

2.3.2.4.2.3 Function

- (1) Photosynthetic reactions take place in chloroplasts.
- (2) Synthesis and storage of starch, lipid occurs in plastids
- (3) Chloroplasts contribute to photosensitivity of some algae.

Know More.

Endosymbiotic Theory

According to the endosymbiotic theory, some of the organelles in today's eukaryotic cells were previously prokaryotic bacteria. The first eukaryotic cell was most likely an amoeba-like cell. It got a nucleus when a section of the cytoplasmic membrane pinched off around the chromosomes. Some of these amoeba-like species engulfed prokaryotic cells, which gradually survived within the organism and developed a symbiotic interaction with the organism. The foreign bacteria eventually lost their cell wall and much of their DNA. Lynn Margulis proposed the theory.

Supportive evidence:

- Mitochondria and chloroplasts have their own circular DNA and own ribosome possessing 30S and 50S subunits like bacteria.
- The mitochondria and chloroplasts are the same size as prokaryotic cells and divide by binary fission. Like bacteria chloroplasts have Fts proteins and mitochondria have Fts homologue protein at their division plane.
- Primitive eukaryotic microbes, like *Giardia* and *Trichomonas*, have a nuclear membrane but no mitochondria.

2.3.2.4.3 Golgi Apparatus

The Golgi apparatus, also known as the Golgi complex or *Apparato Reticulare*, is a complex cell organelle composed of tubules connected by vesicles and vacuoles. The organelle was observed in 1867 by George and named after *Camillo Golgi*, who discovered it using the metallic impregnation method in barn owl and cat nerve cells. In cells that synthesize and secrete complex substances, the Golgi complex is abundant.

It is found in all eukaryotes except mammalian RBC, bryophyte and pteridophyte sperm, and plant sieve tubes. The Golgi complex is absent in prokaryotes. In plant cells,

the Golgi complex is made up of dictyosomes, which are a collection of disconnected components. The Golgi apparatus changes shape and size depending on the cell's physiological state.

2.3.2.4.3.1 Structure

The complex is made of cisternae, tubules, vesicles, and vacuoles.

- **Cisternae:** A stack of membrane-bound cisternae or saccules of varied thicknesses makes up the Golgi complex. Cisternae lumens are 60–90 nm in diameter and contain a matrix substance. The cisternae are usually curved to give the Golgi complex a distinct polarity. Forming face, or *cis*-face, is the convex side, whereas maturing face, or *trans*-face, is the concave side. The medial Golgi stacks are the cisternae in the middle. Transition vesicles transporting secretory biomolecules from the ER enter the *cis*-Golgi, transit through the medial stacks of linked cisternae, and finally bud off as *trans*-face secretion.
- **Tubules:** Tubules form a complex network along the apparatus's periphery and maturing face. They are 30–50 nm in diameter.
- **Vesicles:** Vesicles are tiny sacs with a diameter of 20–80 nm. Smooth and coated types of vesicles are there in cell. The chemicals to be secreted are transported across cisternae by coated vesicles and smooth vesicles or secretory vesicles secrete the chemicals outside the cell.
- **Golgi vacuoles:** Golgi vacuoles are modified cisternae and are made from a concave surface. These vacuoles can sometimes act as lysosomes.

2.3.2.4.3.2 Function

(1) The Golgi apparatus concentrates and packages secretory macromolecules, which are then secreted outside cells via exocytosis or reverse pinocytosis. (2) Glycoproteins and glycolipids are made in the Golgi complex. (3) The Golgi complex is responsible for the formation of specialized structures such as the acrosome of mammalian sperm and the retinal pigment of the chick embryo. (4) The Golgi complex produces cell wall components such as pectic chemicals, mucopolysaccharides, sialic acid, and chondroitin sulphate.

2.3.2.4.4 Endoplasmic Reticulum (ER)

ER is an organized, interconnected labyrinth of membrane-lined channels in the form of branching tubules and flattened sacs in the cytosol. It was discovered by Porter and Thompson independently in 1945. The name ER was coined by Porter in 1953. ER is extensively branched in metabolically active cells like hepatocytes, cells of pancreas. ER is absent in oocytes, RBC, and prokaryotic cells.

2.3.2.4.4.1 Structure

Based on whether ER is studded with ribosomes or not, ER is of two types smooth and rough. Smooth Endoplasmic Reticulum (SER) does not bear ribosomes. SER is present in cells involved in glycogen synthesis and storage. SER is mainly Rough Endoplasmic Reticulum (RER) has ribosomes attached to its outer surface. Two glycoproteins ribophorin I and ribophorin II help in attachment of ribosomes to RER. There are three forms of ER—cisternae, vesicles, and tubules. SER is mostly made of vesicles and tubules, whereas cisternae is the main component of RER.

Cisternae: Cisternae are a bundled pattern of interconnecting sac-like components that remain parallel to each other. The diameter of cisternae is 40–50 nm.

Vesicles: Vesicles are oval or spherical sacs with a diameter of 25–500 nm. Microsomes are another name for vesicles.

Tubules: They are tube-like extensions that form a reticular system when attached to cisternae or vesicles. Their diameter varies between 50 and 100 nm.

2.3.2.4.4.2 Function

(1) ER provides the large surface area for different cellular reactions to occur, (2) ER supports the colloidal cytoplasmic matrix, (3) ER helps in intracellular transport, (4) ER gives rise to vacuoles, (5) ER contains a number of different metabolic enzymes, (6) SER in the form of sarcoplasmic reticulum stores Ca^{2+} required for muscle contraction, (7) SER synthesizes lipid and glycogen, (8) SER helps in metabolism of toxic chemicals and xenobiotics with the help of Cytochrome P-450.

2.3.2.4.5 Peroxisomes

Peroxisome is a small (0.5–1.0 μm in diameter) membrane-enclosed organelle that contains enzymes for several metabolic pathways. Peroxisomes were discovered by De Duve in 1965. Peroxisomes are synthesized from proteins that are translated on free ribosomes and transported to peroxisomes as mature polypeptide chain. Peroxisome is considered as an ‘evolutionary relic’ of protoeukaryotic organelle specialized for oxidation reaction. Peroxisome is covered by single membrane and internal granular matrix contains about 50 oxidative enzymes. Peroxisomes are abundant in photosynthetic cells of plants, liver, and kidney cells. Various oxidative enzymes present in peroxisomes are urate oxidase, α -hydroxy acid oxidase, β -hydroxy acid oxidase, D-amino acid oxidase, catalase, etc.

2.3.2.4.5.1 Functions

(1) **Metabolism of fatty acids:** Long chain and branched chain fatty acids are broken down by peroxisomal enzymes. Peroxisomes generate cholesterol and dolichol in animal cells. Peroxisomes are also involved in the production of bile acids, which are produced from cholesterol, in the liver.

Peroxisomes also contain enzymes that are essential for plasmalogen production. (2) **Metabolism of xenobiotics:** Various uncommon substances or xenobiotics are broken down in peroxisomes. (3) Detoxification of toxic substances like phenolic compounds, nitrites, methanol, ethanol, etc. (4) **Photorespiration** in plants: In photosynthetic plants, photorespiration or oxidative C₂ cycle or the oxidative photosynthetic carbon cycle occurs in peroxisomes. Peroxisomes remain associated with mitochondria and chloroplast. Glycolate from chloroplasts is transported to peroxisomes. Glycolate is oxidized to glyoxylate by catalase in peroxisome. Subsequently, glyoxylate is converted to glycine.

2.3.2.4.6 Ribosomes

Ribosome or *Palade granule* is a complex machinery of protein or polypeptide synthesis. These are subspherical, naked ribonucleoprotein particles with a length of 200–340 Å and diameter of 170–240 Å. Ribosomes are found in cytoplasm, mitochondria, and chloroplast of all eukaryotic cells (except mammalian RBC) and prokaryotic cells. About ten million ribosomes can be found in a rapidly developing mammalian cell.

2.3.2.4.6.1 Composition

In eukaryotes, larger ribosomal subunit 60S is composed of 28S rRNA, 5S rRNA, 5.8S rRNA, and 46 proteins and smaller ribosomal subunit 40S is composed of 18S rRNA and 33 proteins. In prokaryotes, larger ribosomal subunit 50S has 23S rRNA, 5S rRNA, and 33 proteins and smaller subunit 30S has 16S rRNA and 20 proteins. The ribosomes of hepatocytes contain 5–10% lipid.

2.3.2.4.6.2 Structure

Each ribosome is made of two subunits of unequal shape. Larger subunit is dome shaped and double in size of oblate-ellipsoid smaller subunit. The ion Mg^{2+} is required for smaller and larger subunits to attach. Ribosomes can be found alone as *monosomes* or in rosettes and helical groups known as *polyribosomes* and *polysomes*. The cytosolic ribosomes are either found ‘free’ in the matrix or remain ‘bound’ to endoplasmic reticulum with the help of ribophorin protein. The size of ribosomes is expressed as ‘S’ or Svedberg coefficient ($S = 1 \times 10^{-13}$ s). The cytoplasmic ribosomes of eukaryotes are 80S with two subunits, 60S and 40S. In prokaryotes, 70S ribosomes have two subunits 50S and 30S. In mammalian mitochondria, ribosomes are 55S. A ribosome has four sites for specific attachment—(a) mRNA binding site, (b) *A-site* or *aminoacyl site* where mRNA codon and aminoacyl tRNA are directed during translation process, (c) *P-site* or *Peptidyl site* where peptide bond formation, elongation, and transfer of peptide chain to site A occurs, and (d) *E-site* or *Exit site* from where freed tRNA are released after translation.

2.3.2.4.6.3 Function

(1) Ribosomes are sites for translation or protein synthesis. 'Free' ribosomes synthesize structural and enzymatic proteins for use inside cells.

2.3.2.4.7 Lysosomes

Lysosomes are small membrane-bound vesicles containing hydrolytic enzymes in the form of minute crystalline or semicrystalline granules ranging in size from 5 to 8 nm. Christian De Duve discovered lysosomes in 1955. Novikoff et al. (1956) observed these organelles with electron microscopy and named them lysosome. Lysosomes have a spherical shape and a diameter of 0.2–0.8 μm , but their size can vary up to 5 μm depending on the cell type. Different enzymes like lipase, amylase, peptidase, nucleases, and acid phosphatase are present in lysosome. These enzymes are also known as acid hydrolases since they work at acidic pH of 4–5. The influx of H^+ ions into lysosomes keeps the acidic conditions there. The lysosome's covering membrane shields the remaining part of the cell from the acidic lysosomal milieu, while the membrane protects itself via glycosylation of its protein and lipid components. Lysosomes are sometimes called as suicidal bags because they contain a significant number of hydrolytic enzymes.

2.3.2.4.7.1 Function

(1) Intracellular and extracellular digestion are carried out by lysosomes. (2) Lysosomes engulf foreign antigens and harmful substances, assisting the body's natural defence system. (3) Lysosomes are involved in the transformation of numerous creatures, such as amphibians and tunicates. (4) Intracellular scavenging and autophagy occur are facilitated by lysosome.

2.3.2.4.7.2 Lysosomal Storage Diseases in Animal

Lysosomal enzymes break down a wide range of complex macromolecules. Any lysosomal enzyme deficit results in two pathogenic effects: (1) Primary accumulation, i.e. is the accumulation of partially digested insoluble metabolites within the lysosomes; or (2) secondary accumulation, i.e. the build-up of autophagic substrates within the cytoplasm due to reduced lysosomal function. As a result, the harmful proteins accumulate in cell, free radicals are generated, and cell death occurs due to damage to the plasma membrane. Dysfunctions of lysosomal catabolic pathway and subsequent accumulation of macromolecules within the cells lead lysosomal storage disease. In humans, there are about 51 lysosomal storage disorders, and many of these are also found in animals.

2.3.2.4.8 Vacuoles

Inside the cytoplasm, vacuoles are non-cytoplasmic areas separated from the latter by a particular membrane. Vacuoles

originate from ER. In most cells, four types of vacuoles are found based on their content and function.

Sap vacuoles: Fluid or sap-filled vacuoles that are separated from the cytoplasm by a selectively permeable membrane (*tonoplast*). The osmotic pressure of the cell is maintained by various solutes contained in the vacuoles. Food reserves (e.g. sucrose), waste products, pigments (e.g. anthocyanins, anthoxanthins), alkaloids, and other substances may be stored in sap vacuoles.

Contractile vacuoles: These vacuoles are enclosed by a very flexible membrane in some protistan cells like Paramecium. These vacuoles get engorged after receiving water from the cytoplasm, which may or may not include waste materials. Vacuoles that have puffed up come into touch with the plasma membrane and collapse. These vacuoles are involved in osmoregulation and cellular waste excretion.

Food vacuoles: In a few protistan protozoa and phagocytes of higher animals, food vacuoles are generated by the union of lysosome and phagosome. These vacuoles play a role in digestion.

Air vacuoles: Gases are present in these submicroscopic vesicles, which provide buoyancy and mechanical strength to prokaryotic cells.

2.3.2.5 Nucleus

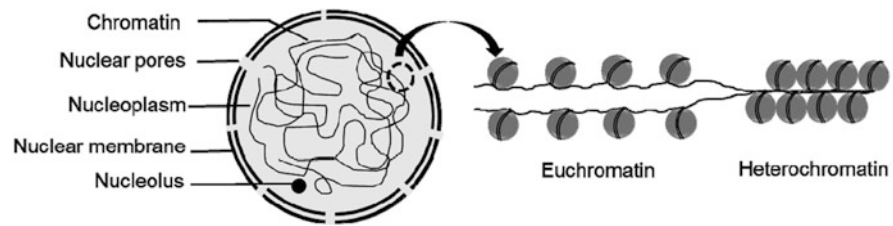
The nucleus is a specialized double membrane-bound protoplasmic entity that houses all of the genetic information needed to control cellular metabolism and pass on to future generations. The nucleus is the biggest cell organelle (interphase nuclei have a diameter of 5–25 μm). Except for mature sieve cells of vascular plants and human RBC, all live eukaryotic cells have a nucleus. Cells typically have a single nucleus, i.e. they are uninucleate. *Paramecium caudatum* contains binucleate cells. Multinucleate cells, also known as syncytial cells, can be found in mammalian muscles, osteoclasts, helminth tegument, glass sponge siliceous spicules, and other places. Coenocytes are multinucleate cells found in plants and fungus, and are commonly seen in Rhizopus, Vaucheria, and other fungi.

2.3.2.5.1 Composition

Acid proteins, neutral proteins and enzymes—65%, Basic proteins—15%, DNA—9–12%, RNA—5%, Lipid—3%, traces of minerals like calcium, magnesium, potassium, and sodium are also present.

2.3.2.5.2 Structure

Nucleus is differentiated into five parts—nuclear envelope, nucleoplasm, nuclear matrix, chromatin, and nucleolus (Fig. 2.7).

Fig. 2.7 Structure of nucleus

- **Nuclear envelope:** The inner and outer membranes of the nuclear envelope make up the nuclear envelope. Each membrane is 60–90 Å thick. The inner membrane is smooth, while the outer membrane is ribosome-studded. The space between inner and outer nuclear membrane is 100–500 Å thick. Nuclear envelope possesses many pores made of nucleoporin protein. The nuclear pores regulate the movement of biomolecules into and out of the nucleus.
- **Nucleoplasm:** Nucleus contains a translucent, semi-fluid, and colloidal substance. It comprises nucleosides as well as a variety of enzymes necessary for the production of DNA, RNA, nucleoproteins, and other nucleic acids.
- **Nuclear matrix:** The nuclear matrix is a network of tiny acidic protein fibrils that serve as a chromatin scaffold. Nuclear lamina, also known as fibrous lamina, is a dense fibrous layer that forms beneath the nuclear membrane. The nuclear matrix contains two types of intermediate filaments: lamin A and lamin B. The nuclear matrix and lamina give the nuclear envelope its mechanical strength.
- **Chromatin:** Chromatin is a nucleoprotein complex found in the reticular structure within nucleus. Euchromatin refers to the light-packed, transcriptionally active areas of chromatin, whereas heterochromatin refers to the condensed form of chromatin. Chromatin fibres condense to produce chromosomes during cell division.
- **Nucleolus:** The nucleolus is a membraneless, round structure within the nucleus that plays an important role in ribosome synthesis. The nucleolus organizer region (NOR) connects the nucleolus to the chromatin. In addition, the nucleolus is involved in the creation of signal recognition particles and the cellular stress response.

2.3.2.5.3 Function

(1) Nucleus is the carrier of hereditary materials called chromatin. Chromatin in the nucleus possesses genetic information necessary for all the functions of cells. (2) The nucleus harbours chromatin, which is a type of hereditary material. The genetic information needed for all of a cell's operations is stored in chromatin in the nucleus. (3) Ribosomes, the protein synthesis factory of the cells, are formed in the nucleolus part of nucleus.

2.3.2.6 Cytoskeleton

The fibrous and tubular structures that make up the cytoskeleton are the structural framework of eukaryotic cells. Cytoskeletal structures maintain the shape of the cell and its appendages and control the distribution of cell organelles, intracellular transport, and cell movement. The three types of filaments are microfilaments, intermediate filaments, and microtubules.

Microfilaments: Microfilaments are the cytoskeletal structures with the smallest diameter (approximately 7 nm). These are double-stranded polymeric fibrous actin (F-actin) molecule. F-actin is made of monomers of globular actin (G-actin). When three G-actin proteins come together to form a trimer, a microfilament begins to form. More actin binds to the barbed end after that. Autoclampin proteins, which operate as motors to assist construct the lengthy strands that make up microfilaments, aid in the self-assembly process. A microfilament is made up of two long strands of actin arranged in a spiral.

Intermediate filaments: Intermediate filaments unbranched cytoskeletal filaments that often form networks. Their average diameter falls between microfilaments and microtubules, ranging from 8 to 10 nm. Intermediate filaments are of variety of shapes and sizes: (1) Keratin filaments: They form tonofibrils and keratin of skin. (2) Neurofilaments: Filaments form lattice with bundles of microtubules in axons and dendrons of neurons. (3) Glial filaments: They are intermediate filaments of astrocytes. (4) Heterogeneous filaments: Synemin filaments, vimentin filaments, and desmin filaments are of these types. These types of intermediate filaments are found in in nucleus and centriole.

Microtubules: Microtubules are rigid hollow rods with a diameter of about 25 nm. Microtubules are composed of a single type of globular protein, called tubulin. Tubulin is a dimer made up of two 55-kDa polypeptides known as α -tubulin and β -tubulin. Microtubules are formed when tubulin dimers polymerize into microtubules, which are made up of 13 linear protofilaments arranged around a hollow core.

2.3.2.6.1 Microtubular Structures

2.3.2.6.1.1 Centrioles

Centrioles are submicroscopic structures having nine triplet fibrils and the ability to create their own duplicates, astral poles, and basal bodies. These are 0.3–0.5 μm in length and 0.15 μm in diameter. The pair of centrioles are known as diplosome and surrounding cytoplasm is called centrosphere. Centrioles are present in eukaryotic animal cells, protozoan protists (except *Amoeba*), and few eukaryotic plants like bryophytes, pteridophytes, and cycads.

Structure

A centriole possesses a cart-wheel structure in transverse section. At the periphery of the wheel, there are 9 peripheral fibrils in 9+0 arrangement. Each fibril is composed of three subfibrils C, B, and A from outside to inside. Sub-fibre A has 13 protofilaments while B and C sub-fibres have less than 13 protofilaments. The adjacent triplet fibrils are connected by C-A proteinaceous linker. The centre of centriole has a proteinaceous mass known as hub. Nine spokes around hub radiate towards the peripheral fibrils. On the outside of centrioles, dense plaques are there known as massules or pericentriolar satellites. Massules act as microtubule organizing centre or MTOC.

Function

(1) Centrioles facilitate in cell division with the formation of MTOC. (2) The distal centriole develops in axial filament or

tail in spermatozoa. (3) Centrioles can develop into basal bodies from which cilia and flagella are formed.

2.3.2.6.1.2 Cilia and Flagella

Cilia and flagella are small hair-like mobile appendages of cells which can produce a current in fluid medium for locomotion or cellular transport of materials. Structurally cilia and flagella are similar and have four parts basal body, rootlets, basal plate, and shaft. The basic difference between them are cilia is smaller (5–20 μm) and more abundant while, flagella is longer (100–200 μm) but fewer (1–4 per cell).

Structure

The different parts of cilia and flagella are:

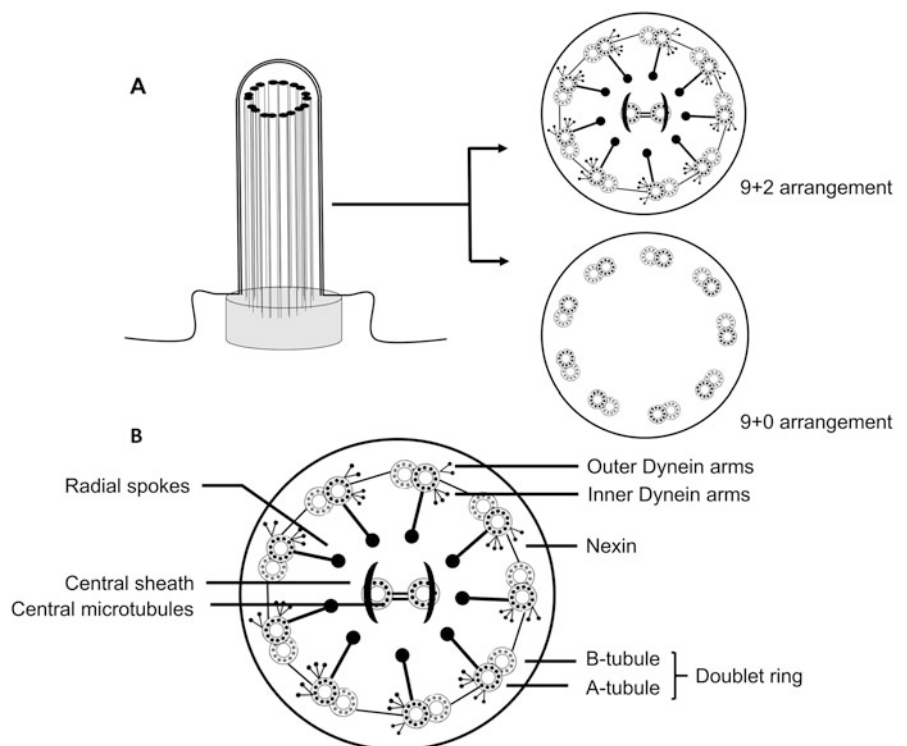
Basal body (Also known as kinetosome, blepharoplast, basal granule): It remains embedded in the periphery of the cytoplasm below the plasma membrane. The structure of basal body is similar to that of centriole.

Rootlets: The rootlets are microfilament bundles developing from the outer part of the basal body and provide support to the basal body.

Basal plate: Basal plate is dense structure above the basal body at the level of cell membrane.

Shaft: Shaft is hair-like projection differing in length. Shaft is covered by an extension of plasma membrane. Inside the shaft axoneme structure is present. Axoneme has 9 doublet fibrils at periphery and 2 singlet fibrils at the centre (9+2 arrangement) (Fig. 2.8a). Each peripheral fibril has two

Fig. 2.8 (a) Structure of cilia and flagella with 9+2 or 9+0 arrangement. (b) Schematic diagram of cross-section of axoneme structure within cilia or flagella



microfibrils or sub-fibres A and B. Sub-fibre A has two bent arms, outer one with a hook. Arms are made of dynein protein. A-B linker made of Nexin protein makes the connection between sub-fibre-B of one fibre and inner side of A-sub-fibre of adjacent fibril (Fig. 2.8b).

Function

(1) Locomotion of flagellate and ciliates is facilitated by cilia and flagella. (2) Cilia helps in transport of gametes in reproductive tract. (3) Cilia sometimes act as sensory organs (cochlear hair cells).

Ciliopathies

Ciliopathies are diseases of human arising from the dysfunction of motile and/or non-motile cilia. Different types of ciliopathies exert phenotypes like retinal degeneration, skeletal malformation, kidney diseases, etc. Examples of ciliopathies are Alström syndrome, Polycystic kidney disease, Bardet–Biedl syndrome, Joubert syndrome, etc.

2.4 Flow of Molecular Genetic Information Within the Cell

The flow of genetic information in cell is illustrated by ‘central dogma’. According to this model, information encoded in DNA is transferred from DNA to RNA and then to proteins via translation. Mechanisms for transmitting information in various forms include reverse transcription (the production of DNA from an RNA template) and replication.

DNA Replication: The basic property of any living organism is to reproduce. The only way to generate new cells is to divide existing ones. So, cell division is essential for the survival of all creatures. DNA contains the genetic information that each cell requires. When a cell splits, all of its DNA must be completely replicated in order to copy the biological information to be passed on to the daughter cell. DNA replication is the name for this process. DNA replication occurs in nucleus of eukaryotic cell.

Transcription: Transcription is the initial stage in gene expression, when information from a gene is used to build a functional product like a protein. The objective of transcription is to create an RNA copy of a DNA sequence of gene. The information needed to make a polypeptide is carried by the RNA copy, or transcript, of a protein-coding gene. Before being translated into proteins, eukaryotic transcripts must go through some processing steps. Transcription occurs in nucleus of

eukaryotic cells. Transcription is regulated at various level by specific interaction of transcription factors, promoters, and other regulatory sequences of DNA which ultimately leads to gene expression control.

Reverse Transcription: Reverse transcription is the process by which double-stranded DNA is created from an RNA template with the help of reverse transcriptase enzyme. Reverse-transcribing RNA viruses (such as *retroviruses*) reverse-transcribe their RNA genomes into DNA with reverse transcriptase, becomes integrated into the host genome and replicates along with it.

RNA Processing: After transcription, newly synthesized RNA, also known as the primary transcript, is further processed before becoming functional. RNA processing differs according to the type of RNA viz. messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA).

Translation: Translation is the process of deciphering messenger RNA (mRNA) and utilizing its information to produce a polypeptide, or chain of amino acids. This process is carried out in the ribosomes present in cytoplasm of the cell.

Know More.....

Genetic Code

In an mRNA, groups of three nucleotides include instructions for making a polypeptide. These are called codon. Sixty-one different codons are there to code different amino acids constituting protein. Three codons (UAA, UAG, and UGA) are ‘stop’ codons that indicate the end of polypeptide synthesis. One codon, AUG, is considered as ‘start’ codon that kicks off translation process. The relationships between mRNA codons and amino acids are known as the genetic code.

Learning Outcomes

- **Cell theory:** Cell theory is one of the fundamental ideas of biology. The tenets to the cell theory are (1) the cell is the fundamental unit of structure and function in living things, (2) all organisms are made up of one or more cells, (3) ‘Omnis cellula e cellula’, i.e. ‘All cells arise from pre-existing cells’. Theodor Schwann, Matthias Schleiden, and Rudolph Virchow are credited with the formulation of the theory.
- **Fluid-mosaic model:** This is the most accepted model of biomembrane, depicted it as dynamic

(continued)

structure with the ability to fuse or separate, expand, or contract during diverse cellular processes. The model was proposed by Singer and Nicolson in 1972.

- **Dictyosome:** In plant cells, the Golgi complex is made up of dictyosomes, which are a collection of disconnected components.
- **ATP Synthase:** Inner membrane and cristae of mitochondria possess small tennis-racket like ATP synthase dimer (earlier known as elementary particles or oxisomes). ATP synthase in eukaryotes consists of two major subunits, FO and F1. The F1 (Fraction 1) part of ATP synthase has three copies of each of subunits α and β , one each of subunits γ , δ , and ϵ . FO subunit consists of a subunit c-ring and one copy each of subunits a, b, d, F6 and the oligomycin sensitivity-conferring protein (OSCP).
- **Photorespiration:** In photosynthetic plants, photorespiration or oxidative C2 cycle or the oxidative photosynthetic carbon cycle occurs in peroxisomes. Peroxisomes remain associated with mitochondria and chloroplast. Glycolate from chloroplasts is transported to peroxisomes. Glycolate is oxidized to glyoxylate by catalase in peroxisome. Subsequently, glyoxylate is converted to glycine.
- **Euchromatin:** Euchromatin refers to the light-packed, transcriptionally active areas of chromatin.
- **Heterochromatin:** Heterochromatin refers to the condensed form of chromatin.
- **Nucleolar Organizer Region (NOR):** NOR is the crucial place of chromosome for the formation of chromosome. NOR connects the nucleolus to the chromatin.
- **9+0 arrangement:** A centriole possesses a cartwheel structure in transverse section. At the periphery of the wheel, there are nine peripheral fibrils in 9+0 arrangement.
- **9+2 arrangement:** Shaft of flagella or cilia has axoneme structure. Axoneme has 9 doublet fibrils at periphery and 2 singlet fibrils at the centre (9+2 arrangement).

Exercises

Objective Questions

- Q1. Which organelle is involved in cell wall synthesis?
 Q2. Which type of membrane protein spans the entire width of the membrane?
 Q3. Desmosomes are concerned with _____.
 Q4. Which is the smallest cell organelle?

- Q5. Which organelle is involved in glycosylation of proteins?
 Q6. Amphisome is the hybrid organelle produced by fusion of _____ and _____.
 Q7. What is the marker enzyme of lysosome?
 Q8. Who coined the term mitochondria?
 Q9. Who built the first microscope?
 Q10. Which cell organelle helps in the formation of root hair?
 Q11. What is the major site of ribosomal RNA synthesis?
 Q12. Who stated '*Omnis cellula e cellula*'?
 Q13. Where is Photosystem I in plants found?
 Q14. Which divalent ion is required for attachment of small and larger subunits of ribosome?
 Q15. How many types of intermediate filaments are found in cell?
 Q16. What is diplosome?
 Q17. What is kinetosome?
 Q18. In which plant cell centriole is found?
 Q19. What are ciliopathies?
 Q20. Who proposed endosymbiont theory?

Subjective Questions

- Q1. What is cellular autonomy in unicellular organism?
 Q2. Describe the structure of plasmodesmata with the help of a diagram.
 Q3. Describe the subunit structure of ATP synthase.
 Q4. Describe different types of vacuoles.
 Q5. Differentiate between microtubules, intermediate filaments, and microfilaments.
 Q6. Describe fluid-mosaic model of cell membrane.
 Q7. Describe the structure of centriole. What are their functions?
 Q8. Describe endosymbiont theory.
 Q9. Name the different types of plastids. Describe the structure of chloroplastid.
 Q10. Describe the ultrastructure of cilia and flagella.
 Q11. What are the functions of Golgi apparatus?
 Q12. What are the chemical compositions of cell membrane?
 Q13. What is the difference between plasma membrane and cell wall?
 Q14. Describe different components of prokaryotic cell.
 Q15. What are the different functional sites of ribosomes? Write their functions.

Answer to Objective Questions

- A1. Golgi Apparatus
 A2. Transmembrane protein
 A3. Cell adherence
 A4. Ribosome
 A5. Golgi complex

- A6. Endosomes, autophagosomes
 A7. Acid phosphatase
 A8. Carl Benda
 A9. Zacharias Janssen
 A10. Golgi apparatus
 A11. Nucleolus
 A12. Rudolph Virchow
 A13. Appressed part of grana
 A14. Mg^{2+}
 A15. Four types
 A16. The pair of centrioles are known as diplosome.
 A17. Basal body of cilia and flagella is also known as kinetosome.
 A18. Bryophytes, pteridophytes, and cycads
 A19. Ciliopathies are diseases of human arising from the dysfunction of motile and/or non-motile cilia.
 A20. Lynn Margulis
- A9. Leucoplast, chromoplast, chloroplast. Chloroplastid—thylakoid, stroma, grana.
 A10. Basal body, rootlets, basal plate, shaft.
 A11. (a) Secretion of biomolecules (b) Synthesis of glycoproteins and glycolipids (c) Formation of specialized structures (d) Synthesis of cell wall components.
 A12. Water-20%, Carbohydrates-1–5%, Lipids-20–79%, Proteins-20–70%.
 A13. Size, occurrence, function.
 A14. Nuclear material, Vacuoles, Ribosomes, Photosynthetic thylakoids, Cell wall, Capsule, Flagella, and fimbriae.
 A15. (a) mRNA binding site, (b) A-site or aminoacyl site where mRNA codon and aminoacyl tRNA are directed during translation process, (c) P-site or Peptidyl site where peptide bond formation, elongation, and transfer of peptide chain to site A occurs, and (d) E-site or Exit site.

Keywords for the Answer to Subjective Questions

- A1. A cell of a unicellular (single celled) organism can exist independently, i.e. it does not depend upon any other cell for any function, material, or information.
 A2. Plasmodesmata are cytoplasmic bridges in the shape of minute pores that connect adjoining plant cells to form a continuous protoplasm. Within plasmodesmata, an endomembrane-derived structure connecting Endoplasmic Reticula (ER) of two adjacent cells (desmotubule) is present.
 A3. F_0 , F_1 particles. F_1 — α and β , one each of subunits γ , δ , and ϵ ; F_0 —a, b, d, F6, and the oligomycin sensitivity-conferring protein (OSCP).
 A4. Sap vacuoles, contractile vacuoles, food vacuoles, air vacuoles.
 A5. Diameters are different.
 A6. Mosaicism, fluidity, asymmetry.
 A7. Cart-wheel structure with 9+0 arrangement. (a) Centrioles facilitate in cell division with the formation of MTOC. (b) The distal centriole develops in axial filament or tail in spermatozoa. (c) Centrioles can develop into basal bodies from which cilia and flagella are formed.
 A8. According to the endosymbiotic theory, some of the organelles in today's eukaryotic cells were previously prokaryotic bacteria.

Further Reading

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