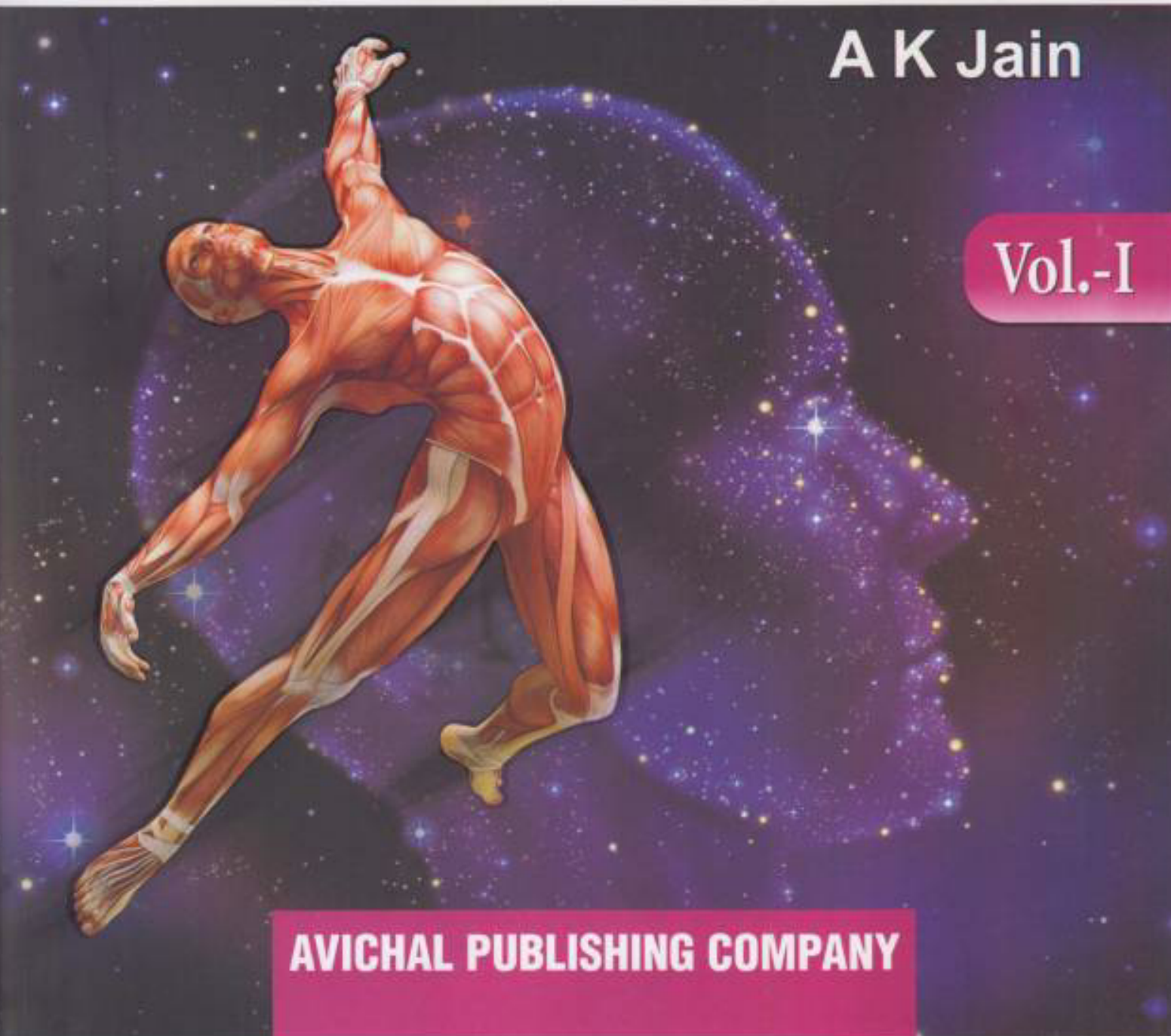
APC

SIXTH EDITION

TEXTBOOK OF PHYSIOLOGY



A K Jain

Vol.-I

AVICHAL PUBLISHING COMPANY

Preface to the First Edition

In my 20 years as a teacher, I have always relished teaching Physiology. It was because of my love for the subject and constant inspiration from my students that I could come up with Textbook of Physiology, which hopefully would lack the inadequacies the students face in other textbooks. In this age when the basic sciences are being vastly updated, this book attempts to summarize the current state of knowledge about the functional organization of the human body, taking care to make learning of the subject an interesting and enriching experience for the students.

Some of the salient features of the book are:

1. A rapid preview has been presented to help the readers to have a bird's eye view of the chapter's content.
2. Well labelled diagrams, flow charts and summarizing tables have been incorporated to make learning easier.
3. Highlighting of important terms has been done by using italics, bold letters or pin-pointing important notes.
4. New concepts and latest developments have been included.
5. The text has been so presented that the student would find it easy to attempt any questions in the form of objective type, multiple choice or essay type after going through the book.
6. Various systemic functions tests have been discussed in detail.
7. Applied aspects of clinically related topics have been discussed.
8. The book has been presented in two volumes for students convenience.

For whom is the book intended? The book is geared to students in health related professions like medicine, dentistry, nursing, occupational therapy, physiotherapy and medical technology. Because of its scope, the text is useful for students in biological sciences.

It is impossible task to come out with a balanced textbook of Physiology, the first time round. Still, I have tried my very best by putting forth my life time's experiences as a teacher into this book. I am aware that I may be having shortcomings in this first effort. Suggestions and new ideas for further improvement of this book shall always be welcomed and widely appreciated.

I could not have even conceived this book, had it not been for the help and encouragement put forth by the undergraduate and postgraduate students of Physiology. Special appreciation is hereby expressed with gratitude for the most assured cooperation provided by all the members of the Department of Physiology, Maulana Azad Medical College, New Delhi. I acknowledge with thanks the valuable time devoted by Dr (Mrs) Urvashi Gupta for correcting the vast manuscript. Dr S. Suresh, an intern, deserves special thanks for his timely valuable contributions.

I extend my heartfelt thanks and sincere regards to Shri V.K. Manchanda and Shri Rajiv Manchanda of M/s. Laser Tech Prints, New Delhi, for giving their valued views for better presentation of this book. I am grateful to Shri Sunil Dutt, Artist, who has given form to my ideas by presenting beautiful diagrams throughout the book.

I am immensely grateful for the support my family members have given me throughout my endeavour. Indebtness is acknowledged and appreciation is expressed to my wife, Smt. Shailesh Jain, nephew Manish and ons Ashish and Avnish, for providing all facilities and keeping me free from all day to day activities to enable ie to complete this book. I owe a great deal of my achievements to my respected mother Shrimati Lajwanti ain and Tauji Shri Man Singh. Without their blessings this book would not have seen the light of the day.

It will be unfair on my part if I fail to pay my gratitude to Dr Vipin Gupta, a unique unmatched personality, who constantly and repeatedly inspired me to start the work on this project.

Finally, I must thank my publishers, M/s. Avichal Publishing Company. Without their sincere efforts my dreams would not have materialized.

Dr A K Jain

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Chapter 1

The Structure and Function of a Cell

I. Introduction – What is physiology?
II. Physiological Systems
III. Homeostatic Regulation
IV. The Structure and Function of a Cell
V. Junctional Complexes Cell Junctions
VI. Apoptosis-programmed cell death

INTRODUCTION —WHAT IS PHYSIOLOGY?

The term ***physiology*** was originally derived from a Greek root with Latin equivalent **Physiologia**, which denoted *natural knowledge*. It now denotes a study of the *functions of the living organism* as a whole or its constituent parts.

1. A study of ***mammalian physiology***, which is a study of the dynamic inter-relationship among different tissues and organs, is mostly carried out at the organism level. The knowledge of physiology is important to appreciate the role of mechanism that control bodily functions.
2. ***Clinical Physiology*** is study of physiological responses or compensatory mechanisms that occur in normal systems when other parts of the body are diseased, for example, the study of changes in the lungs, liver or kidneys when the heart goes into failure.
3. ***Applied Physiology*** is study of underlying mechanisms that control body functions with aging, during exercise, the effects of low or high barometric pressures, oxygen lack, yoga, meditation etc.

Physiology is, therefore, the discipline that deals with the bodily functions and their control. It is however, only concerned with the normal.

PHYSIOLOGICAL SYSTEMS

Fig. 1.1 shows the different **levels of organization** of living organisms. At a fundamental level, **atoms** of elements link together to form mocules. The smallest unit of structure capable of carrying out all life processes is the **cell**. Simple organisms are composed of only one cell, but complex organisms have many cells with different structural and functional speciliazations. Collection of cells that carry out related function are known as *tissues*. Tissues form structural and functional units known as *organs*, and group of organs integrate their functions to create *organ system* (Fig. 1.2) and (Table 1.1).

HOMEOSTATIC REGULATION

In the nineteenth century, *Claude Bernard* (a French Physiologist) was first to recognize the importance of maintaining a stable *internal environment*. The cells, tissues, organs and organ systems of the body are interconnected and live together in a shared (internal) environment. Blood forms internal environment of the cell *i.e.* ***Millieu Interieur*** in terms of *volume, (water) composition, ion concentrations, pH and temperature*. This is regulated to normal (narrow) physiological limits with respect to minor changes in the

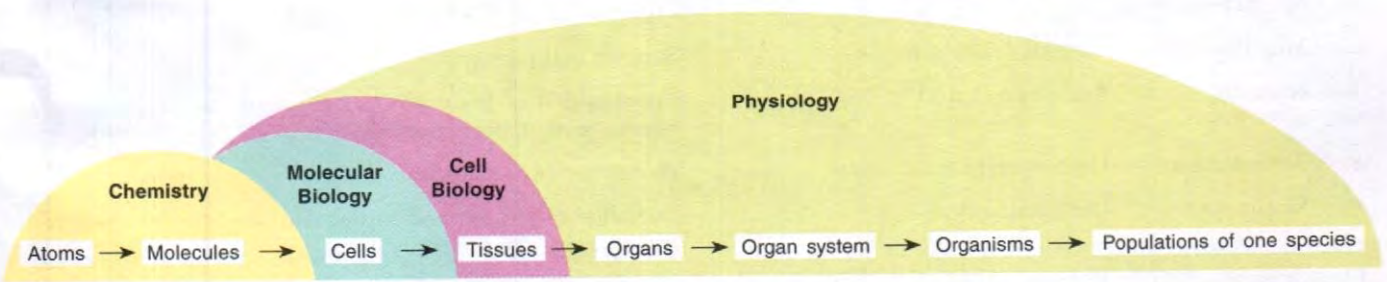

Fig. 1.1 Levels of organization of living organisms

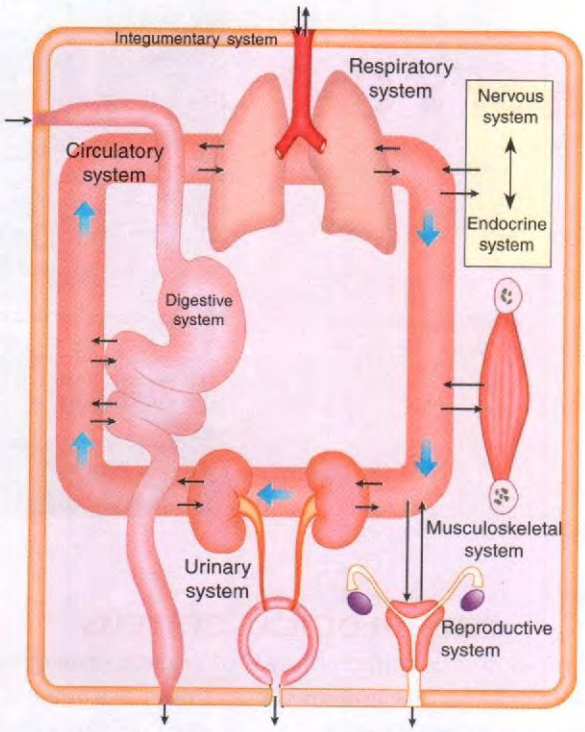

Fig. 1.2 Physiological organ systems in the human body

body. A variety of physiological mechanisms which act to stabilize the internal environment, are called ***Homeostasis Mechanisms*** (A term coined by an American physiologist *W. B. Cannon* in the twentieth century). The adjustments in physiological systems that are responsible for the preservation of homeostasis are referred to as *Homeostatic Regulation*.

Homeostatic regulation usually involves a *receptor*, sensitive to a particular *stimulus* and an *effector* whose activity affects the same stimulus.

(Also refer to pages 507, 557).

A. NEGATIVE FEEDBACK MECHANISMS

Most homeostatic mechanisms involve ***Negative feedback*** *i.e.* a corrective mechanism involving an action that directly opposes a variation from normal limits. Therefore, an increase or decrease in the variable being regulated brings about responses that tend to push the variable in the direction opposite (*negative*) the direction of the original change. For example,

Rise in blood pressure (BP) (*a stimulus*) → via negative feedback mechanism → Decrease in B.P. to normal limits (*response*)

Note

Here the initial stimulus produces a response that depresses the stimulus *i.e.* stimulus and response are opposite to each other.

In general, the *nervous system* performs corrective management by directing rapid, short-term and very specific response. On the other hand, the *endocrine* system releases chemical messengers (*hormones*) that affect tissues and organs throughout the body. The response may be slow to begin with but often persists for days or weeks. However, both systems are usually controlled by negative feedback mechanisms.

Tablel 1.1: Organ Systems of the Human Body

	System Name	Organs (or tissues)	Function(s)
1.	Circulatory	Heart, blood vessels, blood	Transport of materials between all cells of the body
2.	Digestive	Stomach, intestines, liver, pancreas	Conversion of food into particles that can be transported into the body; elimination of wastes
3.	Endocrine	Thyroid gland, adrenal gland etc.	Coordination of body function through synthesis and release of regulatory molecules
4.	Immune	Thymus, spleen, lymph nodes	Defence against foreign invaders
5.	Integumentary	Skin	Protection from external environment
6.	Musculoskeletal	Skeletal muscles, bones	Support and movement
7.	Nervous	Brain, spinal cord	Coordination of body function through electrical signals and release of regulatory molecules
8.	Reproductive	Ovaries and uterus, testes	Production of the species
9.	Respiratory	Lungs, airways	Exchange of oxygen and carbon dioxide between the internal and external environments
10.	Urinary	Kidneys, bladder	Maintenance of water and solutes in the internal environment; waste removal

B. POSITIVE FEEDBACK MECHANISMS

In few instances homeostatic regulation involves ***Positive feedback mechanisms***. *i.e.* an initial disturbance in a system sets off a chain of events that increases the disturbance even further. Therefore, it does not usually favour stability and often abruptly displaces a system away from its steady state operating point.

Example

Marked fall in B.P. (*stimulus*)
↓
Decreased blood supply to the heart
↓
Decrease in myocardial contraction
↓
Further fall in the B.P. (*response*)

Note

Here, the initial stimulus produces response that reinforces (exaggerates) the original stimulus.

Positive feedback mechanism can sometimes be useful:

Example 1.

Injury to blood vessels
↓
Initiates clotting processes
↓
Clotting proceeds
↓
Release of chemicals
↓
Enhances clotting processes
↓
Seals break in blood vessel wall

Example 2. Refer to page 805

(Also refer to page 656)

THE STRUCTURE AND FUNCTION OF A CELL

The fundamental unit of life is a *cell*, since virtually all tissues and any organised activity can be equated to the cellular level. Though no ***typical*** or ***generalised cell*** exists, it is convenient to create one to serve as a conceptual model within which most cell functions can be incorporated. **(Fig. 1.3)**

Note

Most cells in a human being have diameters of 10-20 μm (range 2-120 μm).

The three principal constituents of a cell are:
(A) Cell membrane
(B) Nucleus and its chromosomes
(C) Cytoplasm and its organelles

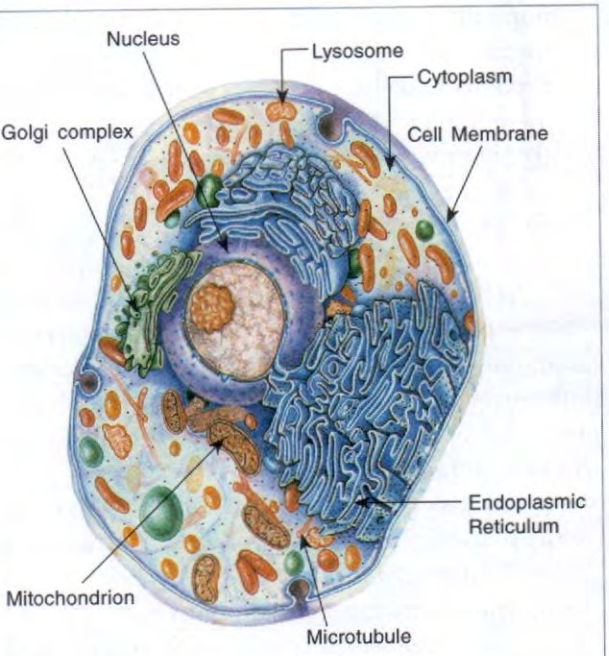

Fig. 1.3 Structure of a Generalised Cell

Note

The clear fluid portion of the cytoplasm in which the particles are dispersed is called *cytosol*.

A. CELL MEMBRANE or PLASMA MEMBRANE or UNIT MEMBRANE

Thickness

70-100 Angstrom (Å) or 7-10 nanometer (nm) (1 nm = 10^{-9} mts; 1Å = 10^{-10} mts).

Structure (Fluid Mosaic Model) (Fig. 1.4)

1. All membranes consist of a double layer of lipid molecules in which proteins are embedded. The lipids

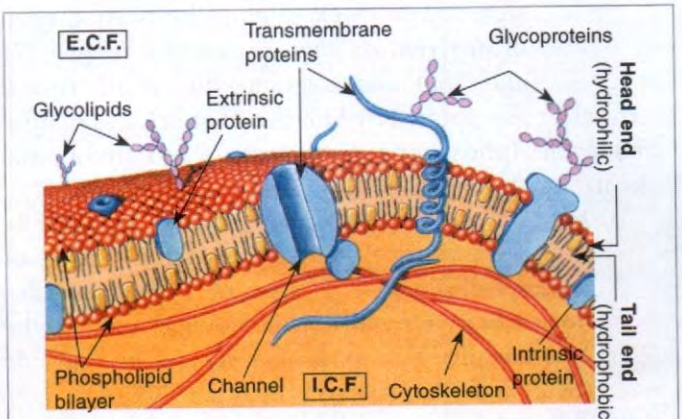

Fig. 1.4 Cell Membrane: Fluid Mosaic Model

normally constitute 20-40% of the dry weight of the membrane.

2. Proteins make upto 60-70% of the dry weight of the membrane and are of 2 types:
   (i) *Lipoproteins* (proteins containing lipids): function as enzymes and ion channels.
   (ii) *Glycoproteins* (proteins containing carbohydrates constituting 1-5% of the dry weight): function as receptors for hormones and neurotransmitters.

Some proteins are located in the inner surface of the membrane (***intrinsic proteins***); some are located in the outer surface of the membranes (***extrinsic*** and ***peripheral proteins***); while some extend through the membrane (***transmembrane proteins***):

(i) Intrinsic proteins serve mainly as 'enzymes'.
(ii) Extrinsic proteins contribute to the *cytoskeleton* (framework of the cell).
(iii) Transmembrane proteins serve as:
   (a) ***Channels***, through which ions or small water soluble substances can diffuse (pages 15 and 521).
   (b) ***Carriers***, which passively or actively transport materials across the lipid layer (pages 20 and 520).
   (c) ***Pumps***, which actively transport ions across the lipid layer (pages 18 and 520).
   (d) ***Receptors***, which when activated initiate intracellular reactions. The number of receptors in a cell are not constant but their number increases and decreases in response to various stimuli, and their properties change with change in physiological condition. For example, when a hormone or neurotransmitter is present in excess, the number of active receptors decreases (called ***down regulation***); whereas during their deficiency, the number of active receptors increases (called ***up regulation***) (Also refer to page 651). These effects on receptors are of physiological significance in explaining the phenomenon of ***denervation hypersensitivity*** (pages 171 and 189) and tolerance to certain drugs.

3. The clear area formed by bimolecular thickness of lipid molecules (phospholipids, cholesterol and glycolipids) is arranged as follows: **(Fig. 1.4)**
   (i) *Head end:* contains phosphate portion, is positively charged and quite soluble in water (*i.e.* **polar** or **hydrophilic**). Polar groups of lipid molecules have affinity for water (water loving) and face the aqueous phase *i.e.* exterior of the cell on one side (ECF) and cytoplasm on the other (ICF).
   (ii) *Tail end:* quite insoluble in water (no affinity for water/water fearing) (*i.e.* **non-polar** or **hydrophobic**), contains two fatty acid chains. The hydrophobic ends facing each other meet in the water-poor interior of the membrane.

Important Note

The bimolecular lipid layer in the membrane has the characteristics of a fluid due to presence of cholesterol. This fluidity makes the membrane quite flexible, thus allows cells to undergo considerable changes in shape without disruption of their structural integrity.

Functions

1. ***Protective*** – it forms outermost boundary of the cell organelles.
2. ***Digestive*** – takes in food and excretes waste products.
3. ***Property of selective permeability:***
   (i) *Non-polar molecules* (gases like O_2, CO_2 and N_2, lipids, steroid hormones, alcohol) can dissolve in the non-polar regions of the membrane and thus move rapidly across the membrane. *Polar molecules* (water soluble substances: ions, glucose, urea etc.) have much lower solubility, therefore, penetrate the membrane much more slowly.
   (iii) Chemical and physical characteristics of the membrane control the free passage of ions and molecules into and out of the cell.

   This property of selective permeability of the cell membrane helps in maintaining the difference of composition between ECF and ICF (page 29).
4. ***Insulating properties:*** It act as the ***dielectric material*** (such as rubber) of a charged condenser, thus the cell membrane has a very high insulating value.
5. It provides a framework for the arrangement of an ordered sequence of protein molecules (enzymes, pumps, receptors, ions, channels, Co-factors, carriers) in a functionally meaningful pattern.
6. It links adjacent cells together by junctional complexes to form tissues (page 10).

Summary: Cell membrane components and Functions **(Fig. 1.5)**

B. NUCLEUS AND ITS CHROMOSOMES

Structure

1. It is a spherical structure (10 µm diameter) surrounded by a relatively permeable membrane called ***nuclear membrane*** (or envelope). This is composed of two unit membranes and shows large pores of 1000 Å diameter which are closed by thin homogenous membrane. Therefore, passage of macromolecules like RNA can take place through these pores. The space between the two folds is 300 Å and is called ***perinuclear cistern***. **(Fig. 1.6)**

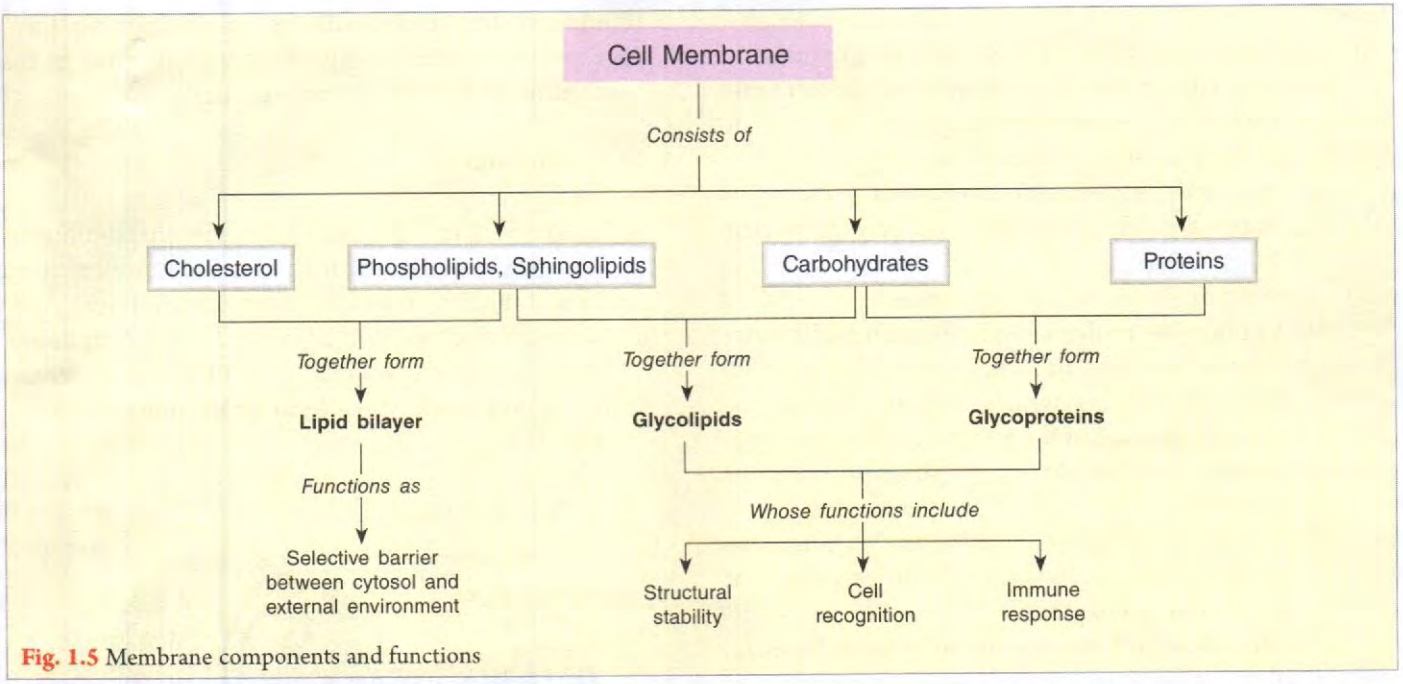

Fig. 1.5 Membrane components and functions

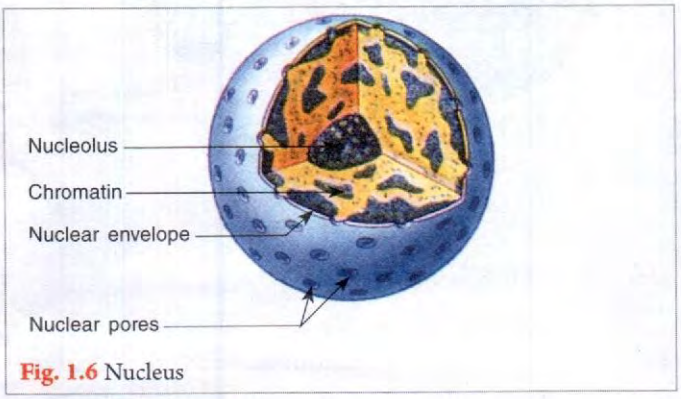

Fig. 1.6 Nucleus

2. It is made up of ***chromosomes*** (each chromosome is made up of supporting protein plus giant molecule of Deoxyribonucleic Acid-DNA), on which genes are present. ***Gene*** is a portion of DNA molecule which carries a complete blue print for all the heritable species and individual characteristics of an animal. During cell division, the pairs of chromosomes become visible, but between cell divisions the irregular clumps of dark material called ***chromatin*** are the only evidence of their presence.
3. It contains a ***nucleolus*** which is densest of all the nuclear material *i.e.* a patch work of granules rich in *Ribonucleic Acid* (RNA). Nucleoli are most prominent and numerous in growing cells. They synthesize the RNA for the ribosomes.

Functions

1. DNA in nucleus serves as a 'template' (block) for synthesis of RNA, which then moves to the cytoplasm where it regulates the synthesis of proteins by the cells. The information coded into the DNA molecules is conveyed from the nucleus to the cytoplasm by messenger RNA where actually the synthetic work of the cell takes place.

Note

80% of the dry weight of nucleus is protein, the remainder is made up by 18% DNA and 2% RNA.

2. Genes are units of hereditary characteristics.
3. It is concerned with cellular reproduction and multiplication; the development of chromosomal threads form the network, being the first step towards cell division.

C. CYTOPLASM AND ITS ORGANELLES

1. Endoplasmic Reticulum (ER)

It is a complex series of tubules whose walls are made up of unit membrane. Through this network of tubules, substances may be delivered from the outer membrane of cell proper to the membrane of the nucleus or to other inclusion bodies of the cells *e.g.* mitochondria **(Fig. 1.7)**.

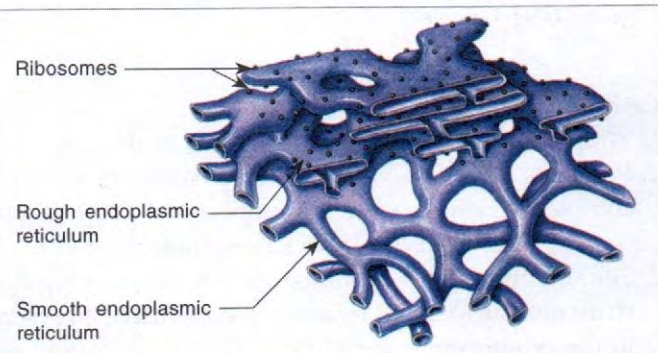

Fig. 1.7 Endoplasmic Reticulum (E.R.)

Types

(i) *Agranular* or *Smooth ER*: Contains no granules.
   (a) It is site of steroid (Adrenocortical hormone) synthesis in steroid secreting cells and the site of detoxification processes in other cells.
   (b) As the *sarcoplasmic reticulum*, it plays important role in skeletal and cardiac muscle (page 160).

(ii) *Granular* or *Rough ER* or *Ergastoplasm*.
   (a) Contains granules called ***ribosomes*** (diameter 15 nm; contains 65% RNA and 35% protein: *Ribonucleoprotein*) which are attached to the cytoplasmic side of the membrane. 3-5 ribosomes clump together to form ***polyribosomes*** or polysomes.
   (b) It is the site of protein synthesis *e.g.*, hormones that are secreted by the cell; and proteins that are found in enzymes.
   (c) Free ribosomes are also found in the cytoplasm, they synthesize cytoplasmic protein *e.g.*, *Haemoglobin*.

2. Golgi Complex (or Golgi Bodies)

It is a collection of membranous tubules and vesicles found always in the neighbourhood of the nucleus, prominent in actively secreting gland cells. **(Fig. 1.8)**

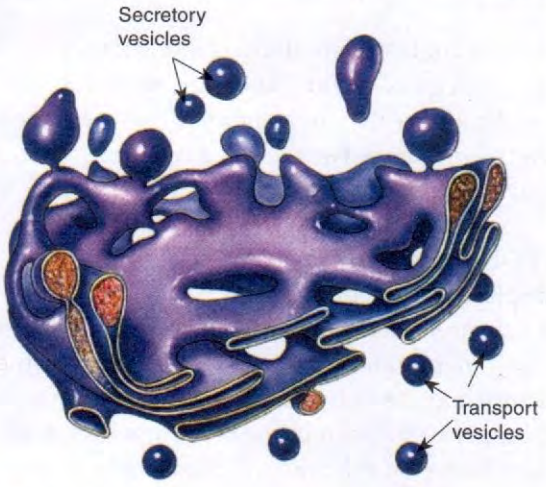

Fig. 1.8 Golgi Complex

Functions

1. Wrapping and packaging department of the cell.
2. Produces *secretion granules i.e.* membrane enclosed complexes, which store hormones and enzymes in protein secreting cells; it packages proteins.
3. Site of formation of *lysosomes i.e.* large irregular structures surrounded by membrane which are present in the cytoplasm.
4. It adds certain carbohydrates to proteins to form glycoproteins, which play an important role in the association of the cells to form tissues.

3. Mitochondrion

Structure

(i) Length 5–12 µm; diameter 0.5–1 µm; filamentous or globular in shape; occur in variable numbers from a few hundred to few thousands in different cells.
(ii) Made up of outer membrane and inner membrane. Inner membrane folded to form *cristae* (shelves) which project into the interior of the mitochondrion. **(Fig. 1.9)**

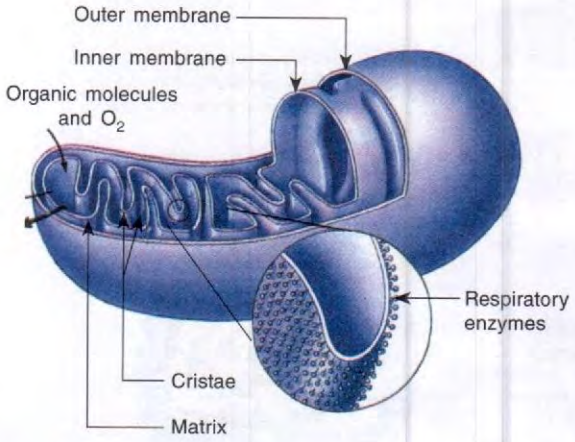

Fig. 1.9 Mitochondrion

(iii) **Outer membrane**: Studded with the enzymes concerned with *biological oxidation* (oxidation being catalyzed by enzymes).
(iv) *Interior (matrix)* of mitochondrion contains enzymes concerned with *'citric acid cycle'* (page 604) and 'respiratory chain oxidation' (page 598).
(v) **Inner membrane** contains adenosine triphosphatase (ATPase) and other enzymes concerned with synthesis and metabolism of ATP.

Functions

(i) Mitochondria are *power generating* units of the cells and are plentiful and best developed in parts of cells where energy requiring processes take place *e.g.* rapidly contracting skeletal muscles where they comprise 40-50% of the cell volume.
(ii) Also contain DNA and can synthesize proteins.

4. Lysosomes

Structure

1. These are large irregular structures surrounded by unit membrane and are found in the cytoplasm;

250-750 nm in diameter. A typical cell may contain several hundred lysosomes.

2. It is filled with large number of small granules, 5-8 nm in diameter which contain variety of enzymes, called ***lysozymes*** **(Table 1.2)**.

Table 1.2: Lysosomal enzymes (lysozymes) and the substrates on which they act

	Enzymes	Substrate
(i)	Ribonuclease	RNA
(ii)	Deoxyribo nuclease	DNA
(iii)	Phosphatase	Phosphate esters
(iv)	Glycosidase	Complex carbohydrates, glycosides and polysaccharides
(v)	Arylsulphatases	Sulphate esters
(vi)	Collagenase	Collagen proteins
(vii)	Cathepsins	Proteins

3. The interior is kept acidic (near pH 5.0) by the action of *proton pump* or H^+ or *ATPase*. Lysozymes are all *acid hydrolases* as they function best at the acidic pH.

Functions

(i) Acts as a form of digestive (lytic) system for the cell, because enzymes present in it can digest essentially all macromolecules.
(ii) Engulf worn out components of the cells in which they are located.
(iii) Engulf exogenous substances *e.g.* bacteria etc. and degrade them.
(iv) When a cell dies, lysosomal enzymes cause autolysis of the remnant *i.e.* why lysosomes are called as *suicidal bags*.

5. Peroxisomes

(i) Its structure is similar to that of lysosomes but with a different chemical composition. It contain *oxidases* (enzymes that produce H_2O_2) rather than hydrolases.
(ii) They consume oxygen in small amounts that is not used in the chemical reactions associated with ATP formation.
(iii) They destroy certain products formed from oxygen, especially hydrogen peroxide, that can be toxic to the cells, hence the name peroxisomes.

Note

The alcohol, a person drinks is mainly detoxified by the peroxisomes of the liver cells.

6. Centrioles or Centrosomes

Structure

(i) These are two short cylinders called '*centrioles*' visible only during cell division.
(ii) They are located at each pole near the nucleus and are so arranged such that they are at right angles to each other.
(iii) Tubules in group of three (triplets) run longitudinally in the walls of the centrioles. There are nine of these triplets spaced at regular intervals around the circumference.

Function

They are concerned with the movement of the chromosomes during cell division.

7. Microtubules and Microfilaments

Microtubules are long hollow structures approx. 25 nm in diameter; make up structures or tracts on which chromosomes, mitochondria and secretion granules move from one part of the cell to another **(Fig. 1.10** and **1.11)**.

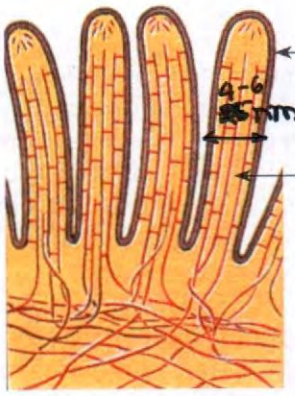

Fig. 1.10 Microtubule

Microfilaments are long solid fibers 4-6 nm in diameter. They comprise the contractile protein actin and are responsible for the cell motion. **(Fig. 1.11)**

Functions

These are involved in the:

(i) movements of the chromosomes;
(ii) cell movement;
(iii) processes that move secretion granules in the cell; and
(iv) movement of proteins within the cell membrane.

8. Secretion Granules: Page 8.

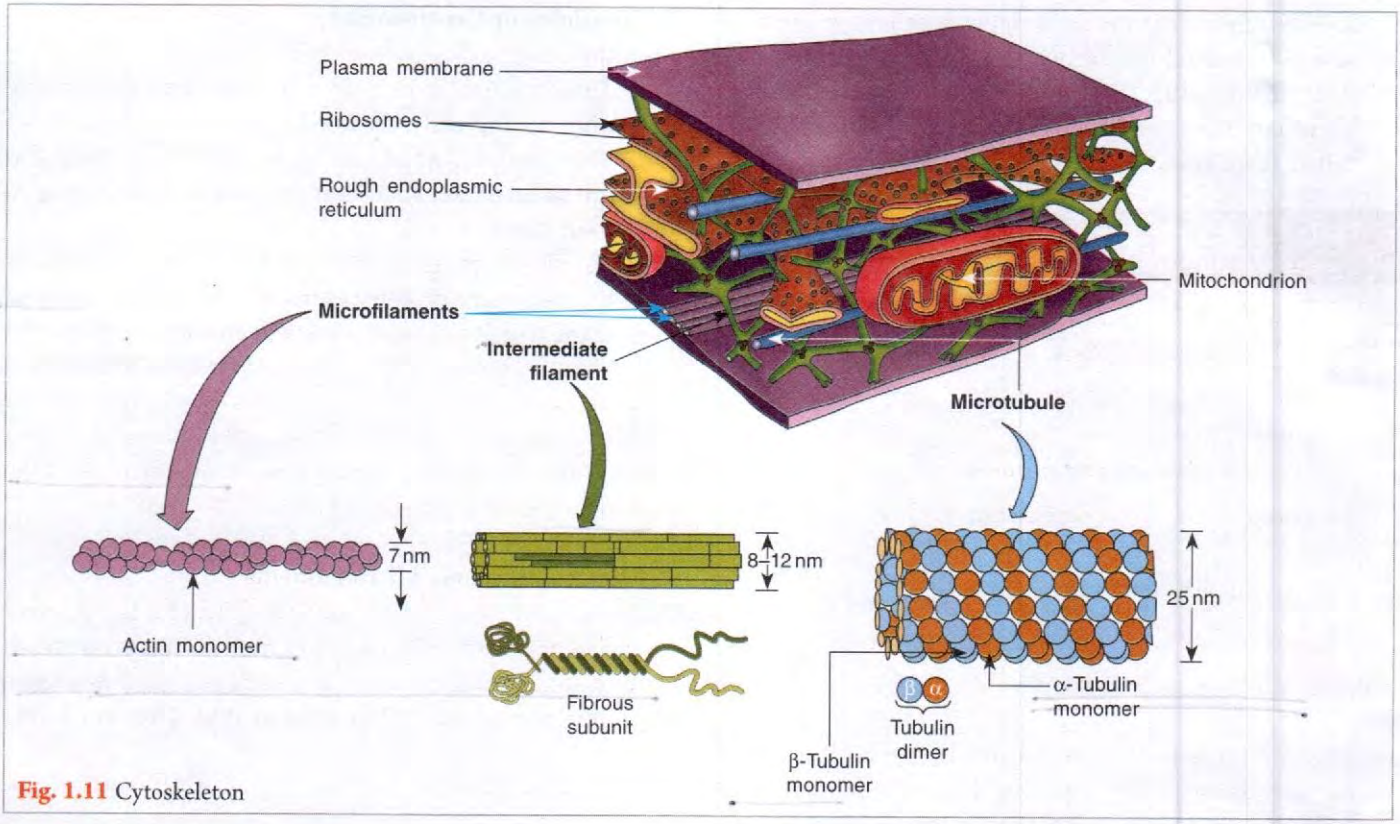

Fig. 1.11 Cytoskeleton

Important Note

All cells have a system of fibers called *cytoskeleton* that maintains the structure of the cell. It allows a cell to change shape and also permits its movement. The cytoskeleton comprises of microtubules and microfilaments, along with proteins that bind them together **(Fig. 1.11)**.

JUNCTIONAL COMPLEXES: CELL JUNCTIONS

The cells are associated into tissues by various means **(Fig. 1.12)**:

1. ***Tight Junction:*** In this, membranes of two cells become opposed and outer layers of the membranes fuse strongly, thus obliterating the space between the cells. This type of junction is characteristically seen along the apical margins of cells in epithelium such as the intestinal mucosa, the walls of the renal tubules, and the choroid plexus. Tight junction forms a barrier to the movement of ions and other solutes from one side of the epithelium to the other.
2. ***Desmosomes or Adherens Junction:*** Here two membranes are separated by a 150-350 Å (15-20 nm) space. There is dense accumulation of proteins on both the surfaces of the membrane with fibers extending from the cytoplasmic surface of each membrane into the cell. This holds adjacent cells firmly together in areas that are subjected to stretching, such as the skin.
3. ***Gap Junction or Nexus:*** There is 2 nm to 20 nm space between the opposing membranes. This gap is filled with densely packed particles through each of which there appears to be a channel that connects the two cells. The diameter of each channel is regulated by intracellular Ca^{2+}, pH and voltage.

   Other advantages of gap junction:

   (i) It permits rapid propagation of electrical potential changes from one cell to another, *e.g.* cardiac and smooth muscle cells (page 175).

   (ii) It permits the direct transfer of ions and other small molecules upto MW 1000 (*e.g.* sugars, amino acids) between the cells without traversing the extracellular space.

Important Note

Cells are attached to each other by ***cell adhesion molecules (CAMs).*** They also transmit signals into and out of the cell. These adhesion proteins (viz. laminin, intergin, IgG, cadherin, selectin) play important role in:

(i) embryonic development
(ii) formation of the nervous system
(iii) holding tissues together
(iv) inflammation and wound healing, and
(v) metastasis of tumours.

Cells with abnormal CAMs have a higher rate of apoptosis (see below).

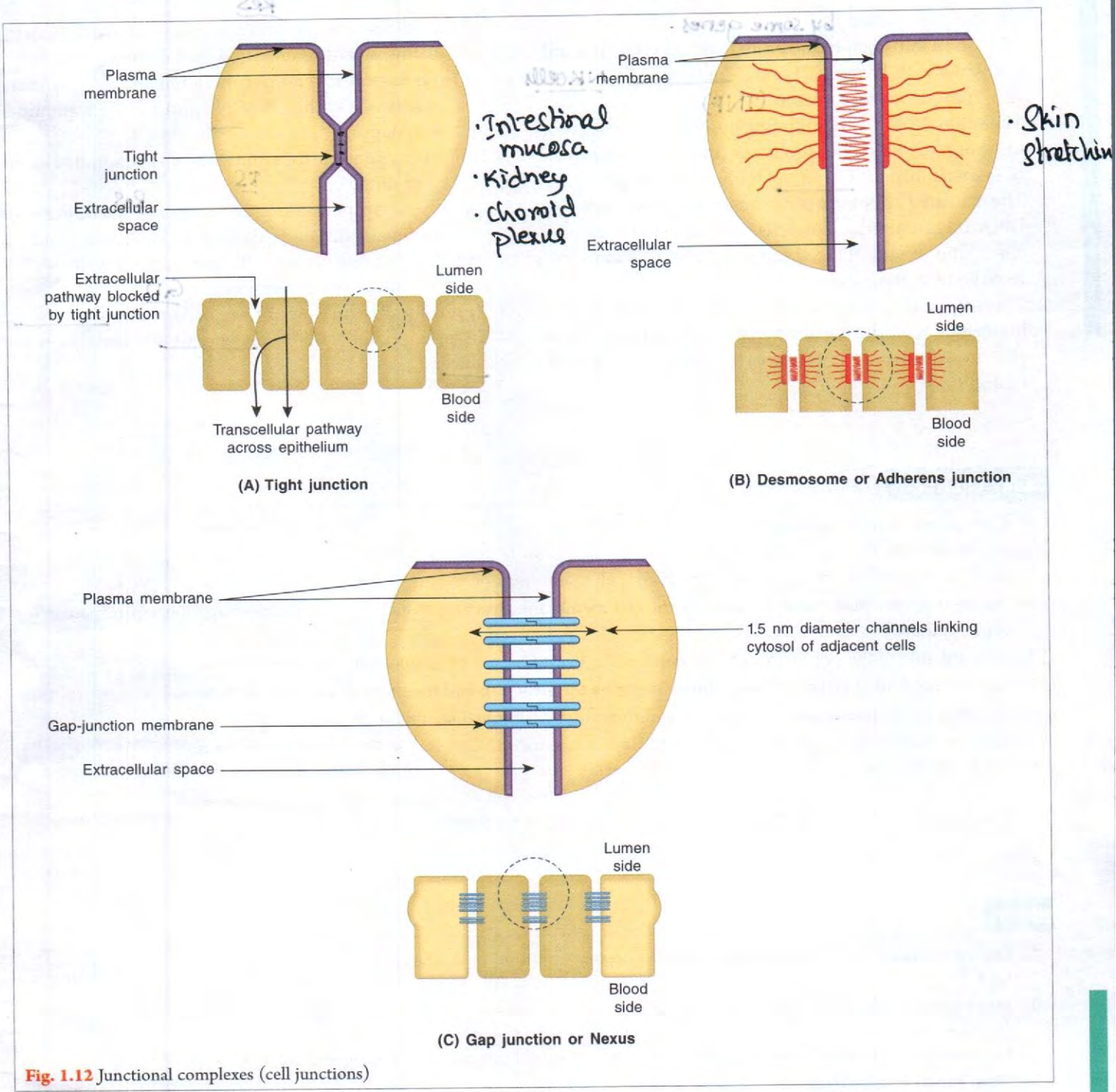

Fig. 1.12 Junctional complexes (cell junctions)

APOPTOSIS: PROGRAMMED CELL DEATH

It is a Greek word which means loosening or falling. (*Apo* means 'away' and *Ptosis* means 'fall')

1. Apoptosis is a process of programmed cell death in which body cells die and get absorbed (phagocytosed) under genetic control. Here cell's own gene plays an active role on its death, therefore, also called as *cell suicide*.

Important Note

Cell necrosis or *cell murder* is a process in which neighbouring healthy cells are destroyed by a disease such as inflammation. However apoptosis is an orderly cell death in which neighbouring cells usually remain healthy.

Mechanism. Apoptosis may be initiated by:

(i) environmental processes such as inflammation

(ii) internal stimuli
(iii) *Fas*, a transmembrane protein produced by natural killer cells (page 122) and T-lymphocyes
(iv) Tumour necrosis factor.

The ultimate pathway initiating apoptosis is activation of group of cysteine proteases inactivate enzymes (together called as, *Caspases*) within the mitochondria. The activated apoptotic gene causes the cell to undergo DNA fragmentation, condensation of cytoplasm and chromatin; finally the cell break up and remnants are removed by phagocytes.

2. ***Physiological significance.*** Apoptosis plays an important role during embryonal development and also in adulthood. It removes un-needed cells. For example,
   (i) it is responsible for regression of duct system during sex differentiation in the foetus;
   (ii) it is responsible for degeneration and regeneration of neurons within the CNS and for the formation of synapse;
   (iii) it is responsible for removal of inappropriate clones of immune cells;
   (iv) it is responsible for cyclical shedding of endometrium at the time of menstruation; and
   (v) it is responsible for cell shed from the tip of the villi in the small intestine.
3. ***Applied.*** Abnormal apoptosis occurs in autoimmune diseases (page 128), degenerative diseases and cancers.

Study Questions

1. **Give physiological significance of:**
   (i) cellular cytoskeleton (ii) Millieu interieur (iii) homeostatic regulation (iv) Junctional complexes
2. **Give the electron microscopic structure of the cell membrane.**
3. **Justify the term 'fluid mosaic model' for the cell membrane structure. Which cell membrane component is responsible for its fluidity?**
4. **Give the role of the cell membrane in maintaining the difference of composition between ECF and ICF.**
5. **List the prominent cell organelles. Briefly describe the structure and functions of any one of them.**
6. **Describe the structure and function of the different types of junctions found between cells.**
7. **Give an account of programmed cell death. How is it initiated? Give its physio-clinical significance.**
8. **Write short notes on:**
   (i) Peroxisomes (ii) Lysosomes (iii) Cell adhesion molecules
   (iv) Negative versus positive feedback mechanisms. (v) Caspases

MCQs

1. **On weight basis, the cell membrane contains protein and lipid in the ratio of:**
   (a) 1:2 (b) 1:1 (c) 2:1 (d) 4:1
2. **One major function of the cell membrane is:**
   (a) Protective (b) Digestive
   (c) Property of selective permeability (d) Links adjacent cells together to form tissues
3. **Main function of nucleus is:**
   (a) To control chemical and physical characteristics of the cell
   (b) To bring about cellular reproduction and multiplication
   (c) To synthesize protein for the cell
   (d) To help in cellular movement
4. **Endoplasmic reticulum is associated with all of the followings *except*:**
   (a) Enzymatic secretion (b) Lipid secretion
   (c) Glycogen synthesis (d) Glycogenolysis
5. **Mitochondria are plentiful and best developed in parts of cells where:**
   (a) Active protein synthesis takes place (b) Energy requiring processes take place
   (c) Active detoxification process is going on (d) Active secretion occurs

6. **Peroxisomes:**
   (a) Their structure and chemical composition is similar to that of lysosomes
   (b) They destroy products formed from oxygen, especially hydrogen peroxide
   (c) They engulf exogenous substances and degrade them
   (d) They consume oxygen in large amounts, hence the name peroxisomes
7. **Cytoskeleton comprises:**
   (a) Microtubules and microfilaments
   (b) Cell membrane
   (c) Golgi complex
   (d) Cell junctions
8. **All are true for gap junction, *except*:**
   (a) It permits rapid propagation of electrical potential changes from one cell to another
   (b) It permits direct transfer of ions between the cells
   (c) It is traversed by a channel that connects the two cells
   (d) It is plentiful in skeletal muscle cells
9. **Which of the following is *false* about apoptosis?**
   (a) It is a process of programmed cell death
   (b) It is also called as cell suicide
   (c) It plays an important role during embryonal development
   (d) It occurs as a natural process in autoimmune diseases
10. **Which of the following moves rapidly across the cell membrane?**
    (a) CO_2 (b) Water (c) Glucose (d) Urea
11. **The bimolecular lipid layer in the cell membrane has the characteristics of a fluid due to presence of:**
    (a) Phospholipids (b) Cholesterol (c) Glycolipids (d) Glycoproteins

Answers

1. (d) 2. (c) 3. (b) 4. (c) 5. (b) 6. (b) 7. (a) 8. (d) 9. (d) 10. (a) 11. (b)

Chapter 2

Transport Across Cell Membranes

I. Passive Transport Processes:
   (A) Diffusion: simple, facilitated (B) Osmosis: osmotic pressure, tonicity
II. Active transport processes:
   (A) Primary (Na^+–K^+ pump)
   (B) Secondary
   (C) Carrier type (uniporters, symporters, antiporters)
   (D) Vesicular transport processes: endocytosis (phagocytosis), pinocytosis, exocytosis
III. Intercellular communication: chemical messengers

Substances move through the cell membrane by two major processes: passive and active. *Passive transport* requires **no** energy; *active transport* on the other hand does consume energy.

PASSIVE TRANSPORT PROCESSES

Here substances move across the cell membrane without any energy expenditure by the cell. It includes: *Diffusion* and *Osmosis*.

A. DIFFUSION

Diffusion is a ***passive process*** (*i.e.* **no** external source of energy is required) by which molecules move from areas of high concentration to areas of low concentration (*down their 'chemical gradient'*); and cations (positively charged molecules) move to negatively charged areas whereas anions move to the positively charged areas (*down their 'electrical gradient'*). It is of two types:
(1) *simple diffusion, and*
(2) *facilitated diffusion.*

1. Simple Diffusion

Characteristic features

(i) It occurs because the heat content of the solution keeps the solvent and the solute particles of the solution in constant motion.
(ii) Net movement stops when the concentration of the molecules is equal everywhere within the solution (***diffusional equilibrium***).
(iii) Although random movements of the molecules continue after diffusional equilibrium is achieved, the concentration of the molecules throughout the solution remains the same.
(iv) It is the only form of transport that is *not* carrier mediated.
(v) *Factors affecting diffusion.* The 'rate' at which a material diffuses through a membrane (flux) is given by *Fick's law of diffusion i.e.*

Net rate of diffusion (flux) =

$$-\frac{\text{Diffusion coefficient (D)} \times \text{Area of the membrane (A)}}{\text{Thickness of membrane (or diffusion distance) (T)}} \times (C_{in} - C_{out})$$

C_{in} and C_{out} = Concentration of the material inside and outside of the membrane. The negative sign indicates that the material is moving down its concentration gradient.

(Also see to page 355)

(a) *Distance:* The greater the distance, the longer the time required. In the human body, diffusion distances are usually small as diffusion of substances occurs across the cell membranes of uniform thickness (10 nm).
(b) *Size of the gradient:* The larger the concentration gradient, faster the diffusion proceeds.
(c) *Temperature:* The higher the temperature, faster the diffusion rate. At normal body temperature of 37°C diffusion is optimal (maximum).
(d) *Molecular size:* The permeability of cell membrane to a substance falls rapidly with increase in molecular weight in the range between 10,000 to 60,000. This is why glucose diffuses faster than large proteins.
(e) *Lipid solubility:*
   – *Lipid soluble molecules* (O_2, CO_2, N_2 and alcohols) diffuse rapidly with ease through the lipid layer of the membrane.