HUMAN ANATOMY, PHYSIOLOGY & PATHOPHYSIOLOGY I

BOOKS FOR BACHELOR OF PHARMACY

- Basics of Python Programming for Pharmaceutical Sciences (Theory)
- General Pharmacy (Theory)
- Healthcare Psychology and Communication Skills (Theory)
- Human Anatomy, Physiology and Pathophysiology I (Theory)
- Introduction to Pharmacognosy (Theory)
- Pharmaceutical Inorganic and Analytical Chemistry (Theory)
- Applied Biostatistics and Data Analytics for Pharmaceutical Sciences (Theory)
- Biochemistry (Theory)
- Human Anatomy, Physiology and Pathophysiology II (Theory)
- Pharmaceutical Organic Chemistry (Theory)
- Pharmacognosy and Phytochemistry (Theory)
- Physical Pharmaceutics (Theory)

Theory & Practical of All Books are available

9 789395 685085

SHREE SAI PRAKASHAN
407/2, New Mohanpuri, Meerut-250002

HUMAN ANATOMY, PHYSIOLOGY & PATHOPHYSIOLOGY I

Dr. Narendra Silawat

ShreeSai's®

Dr. Narendra Silawat

HUMAN ANATOMY, PHYSIOLOGY & PATHOPHYSIOLOGY I

(STRICTLY ACCORDING TO SYLLABUS APPROVED BY PCI FOR B.PHARMA COURSE)

For B. Pharm
1st Sem

SHREE SAI PRAKASHAN

Chapter

1 Introduction to Anatomy and Physiology

The two branches of science provide information about the body parts and their functions in humans namely Anatomy and Physiology.

Anatomy : Anatomy is defined as science of body structure and relationship between them.

Physiology : Physiology is the science of body functions-how the body parts work?

Levels of Structural Organization

Chemical Level : Carbon, hydrogen, nitrogen, phosphorus, calcium and sulphur are essential components to maintain life.

Cellular Level : Molecules combine to form basic structural and functional unit of life-the cell.

Tissue Level : The group of cells and material surrounding them that forms tissue that perform particular functions. Four basic types of tissues in human body are :

1. Epithelial tissues
2. Connective tissues
3. Muscular tissues
4. Nervous tissues

Organ Level

Tissues unite to form organs. Organs are structures that are composed of two or more different tissues that perform specific functions and usually have a definite shape. Examples are stomach, skin, liver, lung etc.

System Level

This level consists of related organs with common functions. The eleven systems of body are :

1. Integumentary System : This is composed of skin, hairs, oil and sweat glands, nails and sensory receptors and its function is to maintain constant body temperature, to protect body and to provide sensory information about the surrounding environment.

2. Skeletal System : The entire framework of bones and their cartilages along with ligaments and tendons is skeletal system. The skeletal system performs functions such as support and protection of body and movement.

3. Muscular System : This system is composed of skeletal muscle tissue and performs the function of production of body movement.

4. Nervous System : Brain, spinal cord, nerves and special sense organs forms nervous system. Generation of nerve impulse to regulate body activities and homeostasis are important functions of nervous system.

5. Endocrine System : Hormone producing glands and hormone producing cells forms endocrine system. Regulation of body activities by releasing hormone is the function of endocrine system.

6. Cardiovascular System : Composed of blood, heart and blood vessels and circulates essential components for maintaining life, also maintains homeostasis by regulating acid base balance.

7. Digestive System : Composed of organs for digestion of food like mouth, pharynx, esophagus, stomach, large and small intestine, salivary glands, liver, gall bladder, pancreas and anus. Functions of digestive system are digestion of food and elimination of solid wastes.

8. Urinary System : Kidneys, ureters, urinary bladder and urethra are the components of urinary system. Urinary system maintains homeostasis by excretion of wastes.

9. Lymphatic and Immune System : Is composed of lymph, vessels, spleen, thymus, lymph nodes and tonsils. Functions of lymphatic and immune system are to return the proteins and fluids to blood, to carry lipids from gastrointestinal tract to blood and protection from disease causing organisms.

10. Respiratory System : Is composed of organs such as trachea, pharynx, larynx, bronchial tubes and lungs and maintains homeostasis by respiration.

11. Reproductive System : Comprises of gonads and associated organs and functions are reproduction of new organism and in continuity of life.

Organismal Level

Any living individual in which all parts of human body functions together.

Introduction to basic anatomical terminology

(A) Body Positions : Description of any region or part of body in a specific stance is called as **anatomical position.**

Prone Position : body is lying face down.

Supine Position : body is lying face up.

(B) Regional Names :

Skull : encloses brain and protects it.

Face : is front portion of head and consist of eyes, nose, forehead, mouth, cheeks and chin.

Neck : Supports head and attaches it to trunk.

Trunk : consists of chest abdomen and pelvis.

Upper Limb : consists of shoulder, armpit, arm, forearm, wrist and hand.

Lower Limb : consist of buttock thigh, leg, ankle and foot.

(C) Directional Terms used in Anatomy and Physiology :

These are the terms that describe the position of one body part in relation to another :

Superior (cephalic or cranial) : towards the head or upper part of structure. The face is superior to the neck.

Inferior (caudal) : Away from head or the lower part of structure. The navel is inferior to the chin.

Anterior (ventral) : nearer to or at front of the body. The windpipe (Trachea) is anterior to the esophagus.

Posterior (dorsal) : nearer to or at back of the body. The heart is posterior to the rib cage.

Medial : nearer to midline. The bridge of the nose is medial to the eyes.

Lateral : farther from midline. The eyes are lateral to the nose.

Intermediate : between the structures. The trabverse colon is intermediate between the ascending and descending colons.

Ipsilateral : on the same side of body as another structure. The gallbladder and ascending colon are ipsilateral.

Contralateral : The opposite side of body from another structure. The ascending and descending colons are contralateral.

Proximal : nearer to origination of structure. The elbow is proximal to the hand.

Distal : farther from origination of structure. The hand is distal to the elbow.

Superficial : towards or on surface of body. The skin is superficial to the muscles.

Deep : away from surface of body. The intestines are deep to the spine

Different body Cavities and Membranes : During embryonic development, the body is first divided into two internal cavities : the posterior (dorsal) body cavity and the anterior (ventral) body cavity. Each of these major cavities is then subdivided into smaller cavities. The cavities, as well as the organs in the cavities (called the **viscera**), are lined by membranes.

Posterior (Dorsal) Body Cavity : The posterior body cavity is subdivided into two parts : (1) The **cranial cavity**, enclosed by the bony cranium, contains the brain. (2) The **vertebral canal**, enclosed by vertebrae, contains the spinal cord. The posterior body cavity is lined by three membranous layers called the **meninges**.

Anterior (Ventral) Body Cavity : The large anterior body cavity is subdivided into the superior thoracic cavity and the inferior abdominopelvic cavity. A muscular partition called the diaphragm separates the two cavities. Membranes that line these cavities are called serous membranes because they secrete a fluid that has just about the same composition as serum, a component of blood. Serous fluid between the smooth serous membranes reduces friction as the viscera rub against each other or against the body wall.

Thoracic Cavity : The thoracic cavity is enclosed by the rib cage, and has three portions : the left, right, and medial portions. The medial portion, called the mediastinum, contains the heart, thymus gland, trachea, esophagus and other structures.

The right and left portions of the thoracic cavity contain the lungs. The lungs are surrounded by a serous membrane called the pleura. The parietal pleura lies

next to the thoracic wall and the visceral pleura adheres to a lung. In between the two pleura, the *pleural cavity* is filled with *pleural fluid*. Similarly, in the mediastinum, the heart is covered by the two-layered membrane called the pericardium. The visceral pericardium which adheres to the heart is separated from the parietal pericardium by a small space called the *pericardial cavity*. This small space contains *pericardial fluid*.

Abdominopelvic Cavity : The abdominopelvic cavity has two portions : the superior abdominal cavity and the inferior pelvic cavity. The stomach, liver, spleen, gall bladder and most of the small and large intestines are in the abdominal cavity. The pelvic cavity contains the rectum, the urinary bladder, the internal reproductive organs, and the rest of the large intestine. Males have an external extension of the abdominal wall, called the scrotum, where the testes are found.

Many of the organs of the abdominopelvic cavity are covered by the visceral peritoneum, while the wall of the abdominal cavity is lined with the parietal peritoneum. Peritoneal fluid fills the cavity between the visceral and parietal peritoneum. Peritonitis is an inflammation of the peritoneum, caused by an infection.

(D) Structural Plan of the Body : The study of anatomy requires positional and directional terminology and reference points.

Planes (sections) of the body are imaginary flat surfaces that pass through it to provide reference points (Fig. 1.1).

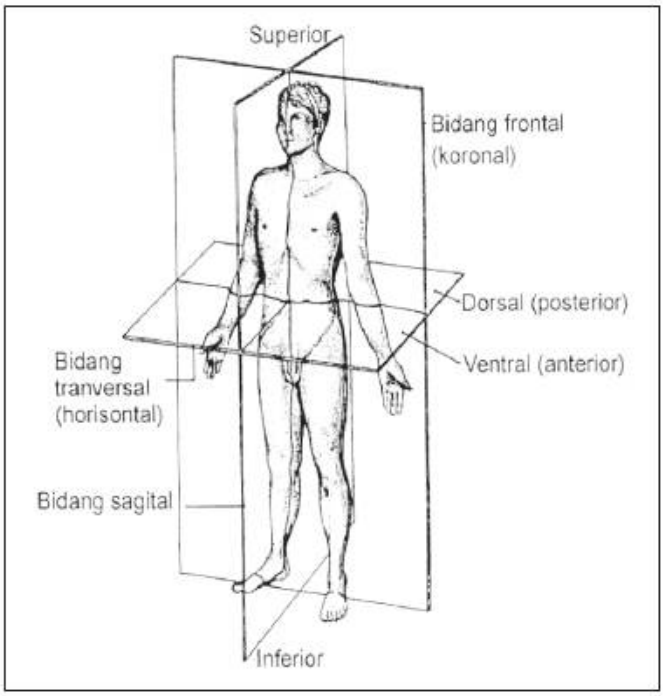

Fig.1.1 : Body Planes and Directions

A sagittal plane divides the body into a right and a left side. A midsagittal plane divides the body into equal right and left halves. A parasagittal plane divides

the body into unequal left and right parts. A frontal or coronal plane is one at right angles to the sagittal plane. It divides the body or organs into front and back parts. A transverse (horizontal, cross-sectional) plane divides the body or organs into upper and lower portions. The anatomical position of the body is used as a reference so that all body parts can be described in relation to it. In anatomical position, the body is erect with eyes forward, feet together, arms at the sides, palms up with the thumbs pointing away from the body, and the little fingers pointing toward the body (Fig1.2). The anterior of the body (ventral in animals) is the front or belly side. For example, the nose is anterior to the rest of the face. The posterior is the back side (dorsal in animals). For example, the buttocks are posterior to the abdomen. Superior is toward the head or uppermost part; it is also referred to as cephalic, craniad, or rostral. For example, the head is superior to the neck.

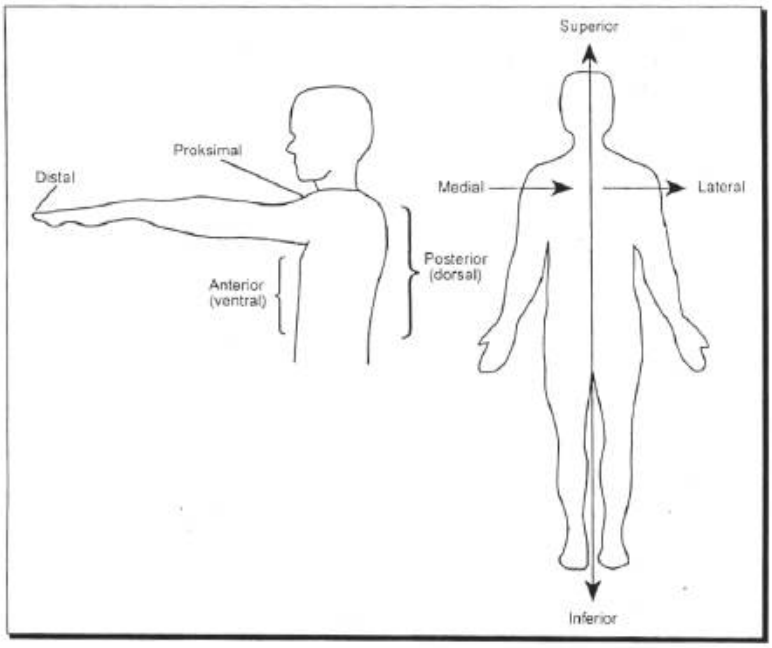

Fig.1.2 : Body Planes and Directions

Homeostasis : Homeostasis is the relative constancy of the body's internal environment. Because of homeostasis, even though external conditions may change dramatically, internal conditions stay within a narrow range. For example, regardless of how cold or hot it gets, the temperature of the body stays around 37°C (97° to 99°F). No matter how acidic your meal, the pH of your blood is usually about 7.4, and even if you eat a candy bar, the amount of sugar in your blood is just about 0.1%. It is important to realize that internal conditions are not absolutely constant; they tend to fluctuate above and below a particular value. Therefore, the internal state of the body is often decribed as one of *dynamic* equilibrium. If internal conditions change to any great degree, illness results. This makes the study of homeostatic mechanisms medically important.

Negative Feedback Mechanism : Negative feedback is the primary homeostatic mechanism that keeps a variable close to a particular value, or set

point. A homeostatic mechanism has three components: a sensor, a regulatory center, and an effector. The sensor detects a change in the internal environment; the regulatory center activates the effector; the effector reverses the change and brings conditions back to normal again. Now, the sensor is no longer activated.

Examples

Regulation of Blood Pressure : When blood pressure falls, sensory receptors signal a regulatory center in the brain. This center sends out nerve impulses to the arterial walls so that they constrict. Once the blood pressure rises, the system is inactivated.

Regulation of Body Temperature : The thermostat for body temperature is located in a part of the brain called the hypothalamus. When the body temperature falls below normal, the regulatory center directs (via nerve impulses) the blood vessels of the skin to constrict. This conserves heat. If body temperature falls even lower, the regulatory center sends nerve impulses to the skeletal muscles, and shivering occurs. Shivering generates heat, and gradually body temperature rises to 37°C. When the temperature rises to normal, the regulatory center is inactivated.

When the body temperature is higher than normal, the regulatory center directs the blood vessels of the skin to dilate. This allows more blood to flow near the surface of the body, where heat can be lost to the environment. In addition, the nervous system activates the sweat glands, and the evaporation of sweat helps lower body temperature. Gradually, body temperature decreases to 37°C.

Positive Feedback Mechanism : Positive feedback is a mechanism that brings about an ever greater change in the same direction. A positive feedback mechanism can be harmful, as when a fever causes metabolic changes that push the fever still higher. Death occurs at a body temperature of 45°C because cellular proteins denature at this temperature and metabolism stops. Still, positive feedback loops such as those involved in blood clotting, the stomach's digestion of protein, and child birth assist the body in completing a process that has a definite cutoff point.

Example

Consider that when a woman is giving birth, the head of the baby begins to press against the cervix, stimulating sensory receptors there. When nerve impulses reach the brain, the brain causes the pituitary gland to secrete the hormone oxytocin. Oxytocin travels in the blood and causes the uterus to contract. As labor continues, the cervix is even more stimulated and uterine contractions become even stronger until birth occurs.

Disease : is present when homeostasis fails and the body (or part of the body) no longer functions properly. The effects may be limited or widespread. A local disease is more or less restricted to a specific part of the body. On the other hand, a systemic disease affects the entire body or involves several organ systems. Diseases may also be classified on the basis of their severity and duration. Acute diseases occur suddenly and generally last a short time. Chronic diseases tend to be less severe, develop slowly, and are long term.

Scope of Anatomy & Physiology : Anatomy and physiology is a subject of paramount scope in all the areas concerned with biomedical and paramedical

sciences including sports and space sciences. Anatomy and Physiology helps us to inquire into fascinating complexity of human body. The knowledge of Anatomy and Physiology still remains as gateway to careers in health related fields. The subject remains as a foundation to advanced scientific studies. Anatomy and Physiology let us know the structures and functions of human body. To perform advanced biomedical research, understanding pathology of disease and pathological changes is must, Anatomy and Physiology is the basic science which provides basic knowledge of this subject. Study of Anatomy helps us in determining techniques of surgeries. It also let us know parameters of normal health and factors affecting various physiological processes and its effects. The knowledge of the subject helps us in overall effective maintenance of individual and community health. Overall the subject is gateway to Medicine and Therapeutics. The knowledge of subject is basic to allied field of healthcare i.e. Mass therapy and Athletics training. The knowledge of Anatomy and Physiology is must in pursuing excellence in physical education sciences.

The knowledge of Anatomy and Physiology is especially important in mastering the subjects in pharmaceutical sciences such as, cell biology, molecular biology, pathophysiology, biopharmaceutics, pharmaceutics, and off course pharmacology (Experimental and clinical).

High Yield Terms to Learn

- **Anatomy :** Anatomy is defined as science of body structure and relationship between them.
- **Disease :** Any deviation from or interruption of the normal structure or function of any body part, organ, or system that is manifested by a characteristic set of symptoms and signs and whose etiology, pathology, and prognosis may be known or unknown.
- **Disorder :** A derangement or abnormality of function; a morbid physical or mental state.
- **Homeostasis :** The condition in which the body's internal environment remains relatively constant within physiological limits.
- **Pathology :** The science which deals with course and nature of disease.
- **Pharmacology :** Pharmacology is science dealing with the study of effect of drug on the function of living system.
- **Physiology :** Physiology is the science of body functions-how the body parts work?
- **Syndrome :** A set of symptoms occurring together; the sum of signs of any morbid state; a symptom complex.

EXERCISE

Fill in the Blanks

1. ..... is defined a science of body structure and relation between them.
2. ..... is study of how the body parts work.

3. When you eat candy bar; the amount of sugar in blood is always 0.1% due to .... equilibrium.
4. When homeostasis fails it result in ..... .
5. Slowly and long term development of disease is called ..... disease.

One Word

1. Structure in one side of body?
2. Structure opposite to each other?
3. Face up position is known as?
4. Pleural fluid is present in?
5. Science which deals with course and nature of disease?
6. Set of symptoms occurring together is called?

Very Short Type Questions

1. What is viscera?
2. What is Prone position?
3. What is supine position?
4. Define Ipsilatereral?
5. Contralateral means?
6. What is superficial?
7. What is pericardial cavity?

Short Answer Type Questions

1. Write a note on positive feedback mechanism?
2. Write a note on Negative feedback mechanism?
3. What is homeostasis?
4. Write a note on structural plain?
5. What is disease?
6. How blood pressure is regulated in body?

Long Answer Type Questions

1. What is scope of Anatomy & Physiology?
2. How body temperature is regulated?

❖ ❖ ❖

Chapter

2 The Cell

The word cell comes from the Latin *cellula*, meaning, a small room. It was discovered by Robert Hooke and is the functional unit of all known living organisms. It is the smallest unit of life that is classified as a living thing, and is often called the building block of life. The cell is the basic functional unit of all living things. The plasma membrane (cell membrane) bounds the cell and encloses the nucleus and cytoplasm. The cytoplasm consists of specialized bodies called organelles suspended in a fluid matrix, the cytosol, which consists of water and dissolved substances such as proteins and nutrients.

The Plasma Membrane

The plasma membrane separates internal metabolic events from the external environment and controls the movement of materials into and out of the cell. The plasma membrane is a double phospholipid membrane (lipid bilayer) with the nonpolar hydrophobic tails pointing toward the inside of the membrane and the polar hydrophilic heads forming the inner and outer faces of the membrane (Fig. 2.1)

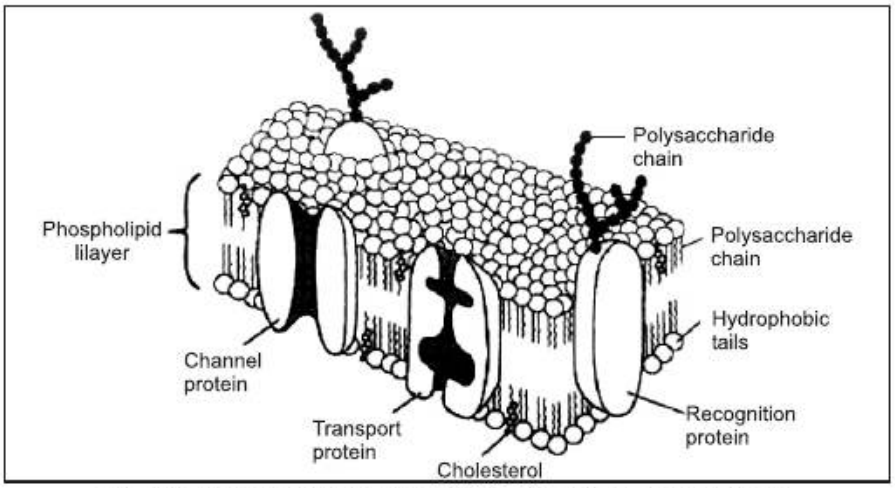

Fig. 2.1. : The Phospholipid Bilayer of the Plasma Membrane

Proteins and cholesterol molecules are scattered throughout the flexible phospholipid membrane. Proteins may attach loosely to the inner or outer surface of the plasma membrane (peripheral proteins), or they may lie across the membrane, extending from inside to outside (integral proteins). The mosaic nature of scattered proteins within a flexible matrix of phospholipid molecules describes the fluid mosaic model of the cell membrane.

Additional Features of the Plasma Membrane are as follows :

- The phospholipid bilayer is selectively permeable. Only small, uncharged, polar molecules, such as H_2O and CO_2, and hydrophobic molecules—nonpolar molecules like O_2 and lipid soluble molecules such as hydrocarbons—can freely cross the membrane.
- Channel proteins provide passageways through the membrane for certain hydrophilic (water-soluble) substances such as polar and charged molecules.
- Transport proteins spend energy (ATP) to transfer materials across the membrane. When energy is used to provide passageway for materials, the process is called active transport.
- Recognition proteins distinguish the identity of neighboring cells. These proteins have oligosaccharide (short polysaccharide) chains extending out from their cell surface.
- Adhesion proteins attach cells to neighboring cells or provide anchors for the internal filaments and tubules that give stability to the cell.
- Receptor proteins initiate specific cell responses once hormones or other trigger molecules bind to them.
- Electron transfer proteins are involved in moving electrons from one molecule to another during chemical reactions.

The Nucleus and Other Organelles

Organelles are bodies within the cytoplasm that serve to physically separate the various metabolic activities that occur within cells (Fig 2.2). They include the following :

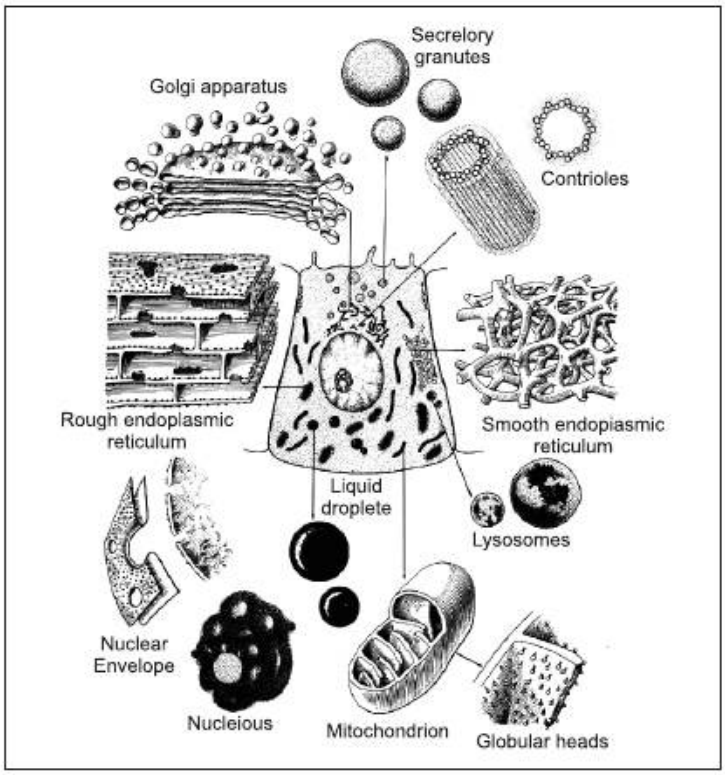

Fig. 2.2. : The General Organization of a Typical Cell

- **The nucleus** is bounded by the nuclear envelope, a phospholipid bilayer similar to the plasma membrane. The nucleus contains DNA (deoxyribonucleic acid), the hereditary information of the cell. Normally, the DNA is spread out within the nucleus as a thread like matrix called chromatin. When the cell begins to divide, the chromatin condenses into rod-shaped bodies called chromosomes, each of which, before dividing, is made up of two long DNA molecules and various histone molecules. The histones serve to organize the lengthy DNA, coiling it into bundles called nucleosomes. Also visible within the nucleus are one or more nucleoli, each consisting of DNA in the process of manufacturing the components of ribosomes. Ribosomes are shipped to the cytoplasm where they assemble amino acids into proteins. The nucleus also serves as the site for the separation of chromosomes during cell division.
- **The endoplasmic reticulum or ER**, consists of stacks of flattened sacs involved in the production of various materials. In cross-section, they appear as a series of maze like channels, often closely associated with the nucleus. When ribosomes are present, the ER (called rough ER) attaches polysaccharide groups to polypeptides as they are assembled by the ribosomes. Smooth ER, without ribosomes, is responsible for various activities, including the synthesis of lipids and hormones, especially in cells that produce these substances for export from the cell. In liver cells, smooth ER is invloved in the breakdown of toxins, drugs, and toxic byproducts from cellular reactions.
- **A Golgi apparatus** (Golgi complex or Golgi body) is a group of flattened sacs arranged like a stack of bowls. They function to modify and package proteins and lipids into vesicles, small, spherically shaped sacs that bud from the ends of a Golgi apparatus. Vesicles often migrate to and merge with the plasma membrane, releasing their contents outside of the cell.
- **Lysosomes** are vesicles from a Golgi apparatus that contain digestive enzymes. They break down food, cellular debris, and foreign invaders such as bacteria.
- **Mitochondrion :** Although the size and shape of mitochondria (sing., **mitochondrion**) can vary, all are bounded by a double membrane. The inner membrane is folded to form little shelves called *cristae*, which project into the matrix, an inner space filled with a gel-like fluid. Mitochondria are the site of ATP (adenosine triphosphate) production involving complex metabolic pathways. ATP molecules are the common carrier of energy in cells. A shorthand way to indicate the chemical transformation that involves mitochondria is as follows :

Mitochondria are often called the powerhouses of the cell : Just as a powerhouse burns fuel to produce electricity, the mitochondria convert the chemical energy of glucose products into the chemical energy of ATP molecules. In the process, mitochondria use up oxygen and give off carbon dioxide and water. The oxygen you breathe in enters cells and then mitochondria; the carbon dioxide you breathe out is released by mitochondria. Because oxygen is involved, we say that mitochondria carry on cellular respiration. The matrix of a mitochondrion contains

enzymes for breaking down glucose products. ATP production then occurs at the cristae. The protein complexes that aid in the conversion of energy are located in an assembly-line fashion on these membranous shelves. Every cell uses a certain amount of ATP energy to synthesize molecules, but many cells use ATP to carry out their specialized functions. For example, muscle cells use ATP for muscle contraction, which produces movement, and nerve cells use it for the conduction of nerve impulses, which make us aware of our environment.

Microtubules, intermediated filaments, and microfilaments are three protein fibers of decreasing diameter, respectively. All are involved in establishing the shape or movements of the cytoskeleton, the internal structure of the cell.

Microtubules are made of the protein tubulin and provide support and mobility for cellular activities. They are found in the spindle apparatus (which guides the movement of chromosomes during cell division) and in flagella and cilia (described later in this list), which project from the plasma membrane to provide motility to the cell.

Intermediate filaments help support the shape of the cell

Microfilaments are made of the protein actin and are involved in cell motility. They are found in almost every cell, but are predominant in muscle cells and in cells that move by changing shape, such as phagocytes (white blood cells that scour the body for bacteria and other foreign invaders).

- ***Flagella*** and ***cilia*** protrude from the cell membrane and make wave like movements. Flagella and cilia are classified by their lengths and by their number per cell : Flagella are long and few; cilia are short and many. A single flagellum propels sperm, while the numerous cilia that line the respiratory tract sweep away debris. Structurally, both flagella and cilia consist of microtubules arranged in a "9 + 2" array—that is, nine pairs (doublets) of microtubules arranged in a circle surrounding a pair of microtubules (Fig. 2.3).
- ***Centrioles*** and ***basal bodies*** act as microtubule organizing centers (MTOCs). A pair of centrioles (enclosed in a centrosome) located outside the nuclear envelope gives rise to the microtubules that make up the spindle apparatus used during cell division. Basal bodies are at the base of each flagellum and cilium and appear to organize their development. Both centrioles and basal bodies are made up of nine triplets arranged in a circle.
- ***Peroxisomes*** are organelles common in liver and kidney cells that break down potentially harmful substances. For example, peroxisomes can convert hydrogen peroxide (a toxin made of H_2O_2), to H_2O.

Cell Junctions

The plasma membranes of adjacent cells are usually separated by extracellular fluids that allow transport of nutrients and wastes to and from the bloodstream. In certain tissues, however, the membranes of adjacent cells may join and form a junction. Three kinds of cell junctions are recognized, as follows :

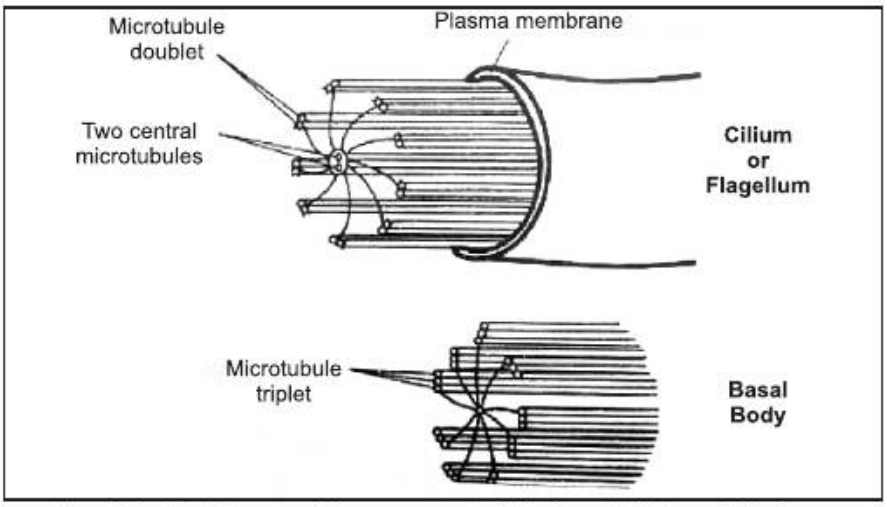

Fig. 2.3 : The Structural Arrangement of Various Cell Specializations

- ***Desmosomes*** are protein attachments between adjacent cells. Inside the plasma membrane, a desmosome bears a disk-shaped structure from which protein fibers extend into the cytoplasm. Desmosomes act like spot welds to hold together tissues that undergo considerable stress (such as skin or heart muscle).
- **Tight junctions** are tightly stitched seams between cells. The junction completely encircles each cell, preventing the movement of material between the cell. Tight junctions are characteristic of cells lining the digestive tract, where materials are required to pass through cells (rather than intercellular spaces) to penetrate the bloodstream.
- ***Gap junctions*** are narrow tunnels between cells that consist of proteins called connexons. The proteins allow only the passage of ions and small molecules. In this manner, gap junctions allow communication between cells through the exchange of materials or the transmission of electrical impulses.

Movement of Substances : The following terms are used to describe the movement of substances into, out of, and between cells :

- The movement of substances may occur across a selectively permeable membrane (such as the plasma membrane). A selectively permeable membrane allows only specific substances to pass.
- The substances, whose movements are being described, may be water (the solvent) or the substance dissolve in the water (the solute).
- Movement of substances may occur from higher to lower concentrations (down the concentration gradient) or the opposite direction (up or against the gradient).
- Solute concentrations vary. A solution may be hypertonic (a higher concentration of solutes), hypotonic (a lower concentration of solutes), or isotonic (an equal concentration of solutes) compared to another region.
- The movement of substances may be passive or active. Usually occurring against the gradient, active movement requires the expenditure of energy.

Passive Transport Process

Passive transport describes the movement of substances down a concentration gradient and do not require energy consumption.

- Bulk flow is the collective movement of substances in the same direction in response to a force, such as pressure. Blood moving through a blood vessel is an example of bulk flow.
- Simple diffusion, or diffusion, is the net movement of substances from an area of higher concentration to an area of lower concentration. This movement occurs as a result of the random and constant motion characteristic of all molecules (atoms or ions) and is independent from the motion of other molecules. Since, at any one time, some molecules may be moving against the gradient and some molecules may be moving down the gradient (remember, the motion is random), the word "net" is used to indicate the overall, eventual end-result to the movement. If a concentration gradient exists, then the molecules (which are constantly moving) will eventually become evenly distributed (a state of equilibrium).

Osmosis

Osmosis is the diffusion of water across a plasma membrane. It occurs whenever an unequal concentration of water exists on either side of a selectively permeable membrane. Normally, body fluids are isotonic to cells that is, there is an equal concentration of solutes (substances) and solvent (water) on both sides of the plasma membrane, and cells maintain their usual size and shape. Intravenous solutions medically administered usually have this tonicity.

Tonicity is the degree to which a solution's concentration of solute versus water causes water to move into or out of cells. Solutions (solute plus solvent) that cause cells to swell or even to burst due to an intake of water are said to be hypotonic solutions. If red blood cells are placed in a *hypotonic* solution, which has a higher concentration of water (lower concentration of solute) than the cells, water enters the cells and they swell to bursting. The term lysis refers to disrupted cells; hemolysis, then, is disrupted red blood cells.

Solutions that cause of cells to shrink or to shrivel due to a loss of water are said to be hypertonic solutions. If red blood cells are placed in a hypertonic solution, which has a lower concentration of water (higher concentration of solute) than do the cells, water leaves the cells and they shrink (Fig. 2.4).

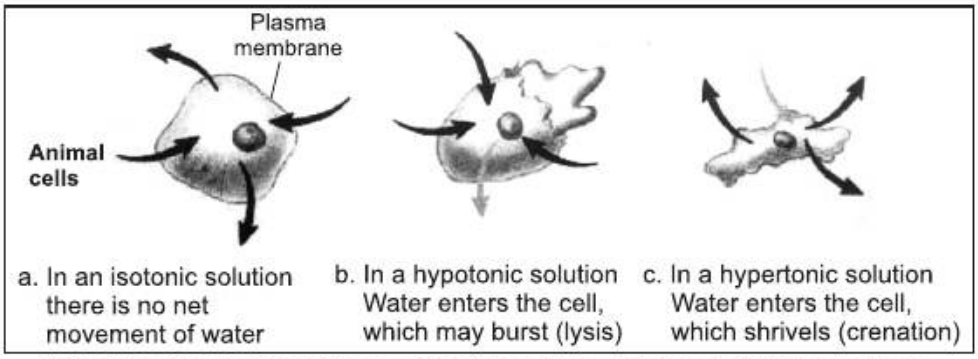

Fig. 2.4. : Effect of Tonicity on cells : (a) isotonic, (b) hypotonic (c) hypertonic

The term crenation refers to red blood cells in this condition. These changes have occurred due to osmotic pressure.

Osmotic pressure is the force exerted on a selectively permeable membrane because water has moved from the area of higher concentration of water to the area of lower concentration (higher concentration of solute).

Dialysis is the diffusion of solutes across a selectively permeable membrane.

Facilitated diffusion is the diffusion of solutes through channel proteins in the plasma membrane. Note that water can pass freely through the plasma membrane without the aid of specialized proteins.

- Channel mediated
- Carrier mediated

Active Transport Processes

Active transport is the movement of solutes against a gradient and requires the expenditure of energy (usually ATP). Active transport is achieved through one of the following two mechanisms :

- Transport proteins in the plasma membrane transfer solute such as small ions (Na^+, K^+, Cl^-, H^+), amino acids, and monosaccharides.

Table 2.1 Transport Process Across the Cell Membrane

Methods	Name	Direction	Requirement	Examples
Passive methods	Diffusion	Toward lower Concentration	Concentration gradient	Lipid-soluble molecules, water, and gases
	Facilitated transport	Toward lower concentration	Carrier and concentration gradient	Sugars and amino acids
Active Methods	Active transport	Toward higher concentration	Carrier plus energy	Sugars, amino acids, and ions
	Endocytosis (phagocytosis)	Toward inside	Vesicle formation	Macromolecules
	Exocytosis	Toward outside	Vesicle fuses with plasma membrane	Macromolecules

- Vesicles or other bodies in the cytoplasm move macromolecules or large particles across the plasma membrane. Types of vesicular transport include :

Exocytosis, which describes the process of vesicles fusing with the plasma membrane and releasing their contents to the outside of the cell. This process is common when a cell produces substances for export.

Endocytosis, which describes the capture of a substance outside the cell when the plasma membrane merges to engulf it. The substance subsequently enters the cytoplasm enclosed in a vesicle. There are three kinds of endocytosis :

Phagocytosis ("cellular eating") occurs when undissolved material enters the cell. The plasma membrane engulfs the solid material, forming a phagocytic vesicle.

Pinocytosis ("cellular drinking") occurs when the plasma membrane folds inward to form a channel allowing dissolved substances to enter the cell. When the channel is closed, the liquid is encircling within a pinocytic vesicle.

Receptor-mediated endocytosis occurs when specific molecules in the fluid surrounding the cell bind to specialized receptors in the plasma membrane. As in pinocytosis, the plasma membrane folds inward and the formation of a vesicle follow. Certain hormones are able to target specific cells by receptor-mediated endocytosis.

Cell Division

Cell division consists of two phases, nuclear division followed by cytokinesis. Nuclear division divides the genetic material in the nucleus, while cytokinesis divides the cytoplasm. There are two kinds of nuclear division—mitosis and meiosis. Mitosis divides the nucleus so that both daughter cells are genetically identical. In contrast, meiosis is a reduction division, producing daughter cells that contain half the genetic information of the parent cell.

The first step in either mitosis or meiosis begins with the condensation of the genetic material, chromatin, into tightly coiled bodies, the chromosomes. Each chromosome is made of two identical halves called sister chromatids, which are joined at the centromere. Each chromatid consists of a single, tightly coiled molecule of DNA. Somatic cells (all body cells except eggs and sperm) are diploid cells because each cell contains two copies of every chromosome. A pair of such chromosomes is called a homologous pair. In a homologous pair of chromosomes, one homologue originates from the maternal parent, the other from the paternal parent. There are 46 chromosomes, 23 homologous pairs, consisting of a total of 92 chromatids.

When a cell is not dividing, the chromatin is enclosed within a clearly defined nuclear envelope, one or more nucleoli are visible within the nucleus, and two centrosomes (each containing two centrioles) lie adjacent to one another outside the nuclear envelope. These features are characteristic of interphase, the nondividing but metabolically active period of the cell cycle (fig. 2.5). When cell division begins, these features change, as described in the following sections.

Mitosis

There are four phases in mitosis (adjective, mitotic) : prophase, metaphase, anaphase and telophase.

- ***Prophase,*** the nucleoli disappear, the chromatin condenses into chromosomes, the nuclear envelope breaks down, and the mitotic spindle is assembled. The development of the mitotic spindle begins as the centrosomes move apart to opposite ends (poles) of the nucleus. As they move apart, microtubules develop from each centrosome, increasing in length by the addition of tubulin units. Microtubules from each centrosome connect to specialized regions in the centromere called kinetochores. Microtubules tug on the kinetochores, moving the chromosomes back and forth, toward one pole, then the other. Within the spindle, there are also microtubules that overlap at the center of the spindle and do not attach to the chromosomes.

- ***Metaphase*** begins when the chromosomes are distributed across the metaphase plate, a plane lying between the two poles of the spindle. Metaphase ends when the microtubules, still attached to the kinetochores, pull each chromosome apart into two chromatids. Each chromatid is complete with a centromere and kinetochores. Once separated from its sister chromatid, each chromatid is called a chromosome. (To count the number of chromosomes at any one time, count the number of centromeres.)
- ***Anaphase*** begins after the chromosomes are separated into chromatids. During anaphase, the microtubules connected to the chromatids (now chromosomes) shorten, effectively pulling the chromosomes to opposite poles. Overlapping microtubules originating from opposite centrosomes but not attached to chromosomes interact to push the poles farther apart. At the end of anaphase, each pole has a complete set of chromosomes, the same number of chromosomes as the original cell. (Since it consists of only one chromatid, each chromosome contains only a single copy of the DNA molecule.)
- ***Telophase*** concludes the nuclear division. During this phase, a nuclear envelope develops around each pole, forming two nuclei. The chromosomes within each of these nuclei disperse into chromatin, and the nuclei reappear. Simultaneously, cytokinesis occurs, dividing the cytoplasm into two cells. Microfilaments form a ring inside the plasma membrane between the two newly forming nuclei. As the microfilaments shorten, they act like purse strings to pull the plasma membrane into the center, dividing the cell into two daughter cells. The groove that forms as the purse strings are tightened is called a cleavage furrow.

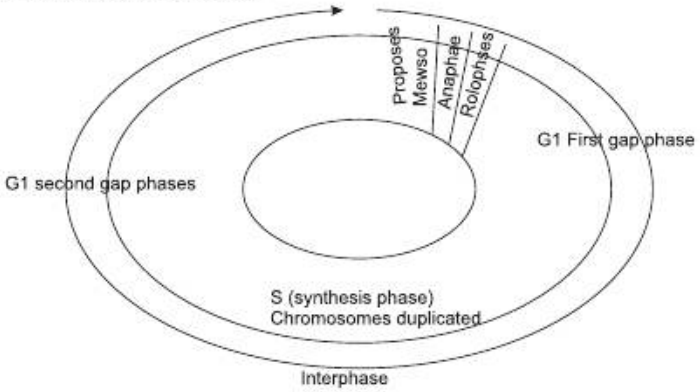

Fig. 2.5. The Cell Cycle Phases

Once mitosis is completed and interphase begins, the cell begins a period of growth. Growth begins during the first phase, called G1, and continues through the S and G2 phases. Also during the S phase the second DNA molecule for each chromosome is synthesized. As a result of this DNA replication, each chromosome gains a second chromatid. During the G2 period of growth, materials for the next

mitotic division are prepared. The time span from one cell division through G1, S, and G2 is called a cell cycle.

A cell that begins mitosis in the diploid state—that is, with two copies of every chromosome—will end mitosis with two copies of every chromosome. However, each of these chromosomes will consist of only one chromatid, or one DNA molecule.

During interphase, the second DNA molecule is replicated from the first, so that when the next mitotic division begins, each chromosome will, again, consist of two chromatids (fig. 2.6.)

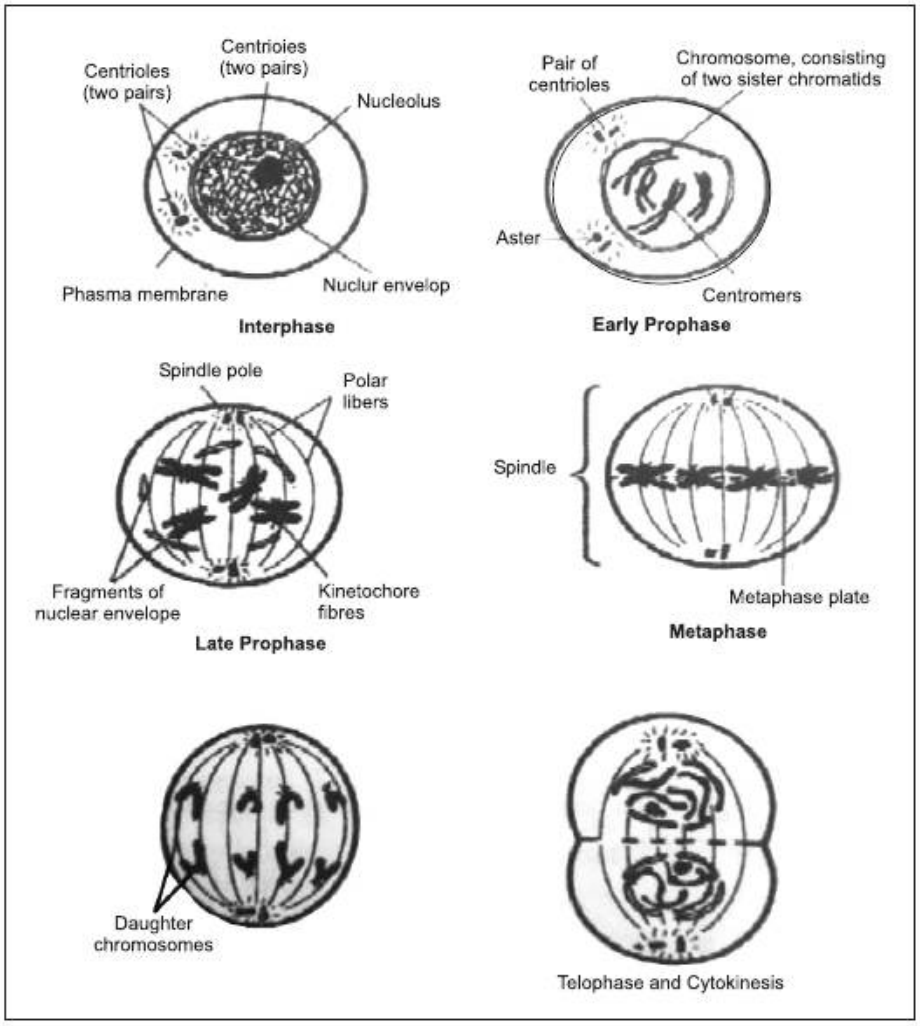

Fig. 2.6. Steps involved in Mitosis

Importance of Mitosis

Because of mitosis, each cell in our body is genetically identical, meaning that it has the same number and kinds of chromosomes. Mitosis is important to the growth and repair of multicellular organisms. When a baby develops in the

mother's womb, mitosis occurs as a component of growth. As a wound heals, mitosis occurs, and the damage is repaired.

Meiosis

Meiosis (adjective, meiotic) is very similar to mitosis. The major distinction is that meiosis consists of two groups of division, meiosis I and meiosis II. In meiosis I, homologous chromosomes pair at the metaphase plate and then migrate to opposite poles. In meiosis II, chromosomes spread across the metaphase plate, and sister chromatids separate and migrate to opposite poles. Thus, meiosis II is analogous to mitosis. A summary of each meiotic stage follows (Fig. 2.7.).

- ***Prophase I*** begins like prophase of mitosis. The nucleolus disappears, chromatin condenses into chromosomes, the nuclear envelope breaks down, and the spindle apparatus develops. Once the chromosomes are condensed, however, their behavior differs from mitosis. During prophase I, homologous chromosomes pair, a process called synapsis. These pairs of homologous chromosomes are called tetrads (a group of four chromatids) or bivalents. During synapsis, corresponding regions form close associations called chiasmata (singular, chiasma) along nonsister chromatids. Chiasmata are sites where genetic material is exchanged between nonsister homologous chromatids, a process called crossing over. The result contributes to a mixing of genetic material from both parents, a process called genetic recombination.
- ***Metaphase I***, homologous pairs of chromosomes are spread across the metaphase plate. Microtubules extending from one pole are attached to kinetochores of one member of each homologous pair. Microtubules from the other pole are connected to the second member of each homologous pair.
- ***Anaphase I*** begin when homologues within tetrads uncouple as they are pulled to opposite poles.
- ***Telophase I***, the chromosomes have reached their respective poles, and a nuclear membrane develops around them. Note that each pole will form a new nucleus that will have half the number of chromosomes, but each chromosome will contain two chromatids. Since daughter nuclei will have half the number of chromosomes, cells that they eventually form will be haploid.
- Cytokinesis occurs forming two daughter cells. A brief interphase may follow, but no replication of chromosomes occurs. Instead, part II of meiosis begins in both daughter nuclei.
- **Prophase II,** the nuclear envelope disappears, and the spindle develops. There are no chiasmata and no crossing over of genetic material as in prophase I.
- **Metaphase II,** the chromosomes align singly on the metaphase plate (not in tetrads as in metaphase I). Single alignment of chromosomes is exactly what happens in mitosis—except now there is only half the number of chromosomes.
- **Anaphase II** begins as each chromosome is pulled apart into two chromatids by the microtubules of the spindle apparatus. The chromatids

(now chromosomes) migrate to their respective poles. Again, this is exactly what happens in mitosis—except now there is only half the number of chromosomes.

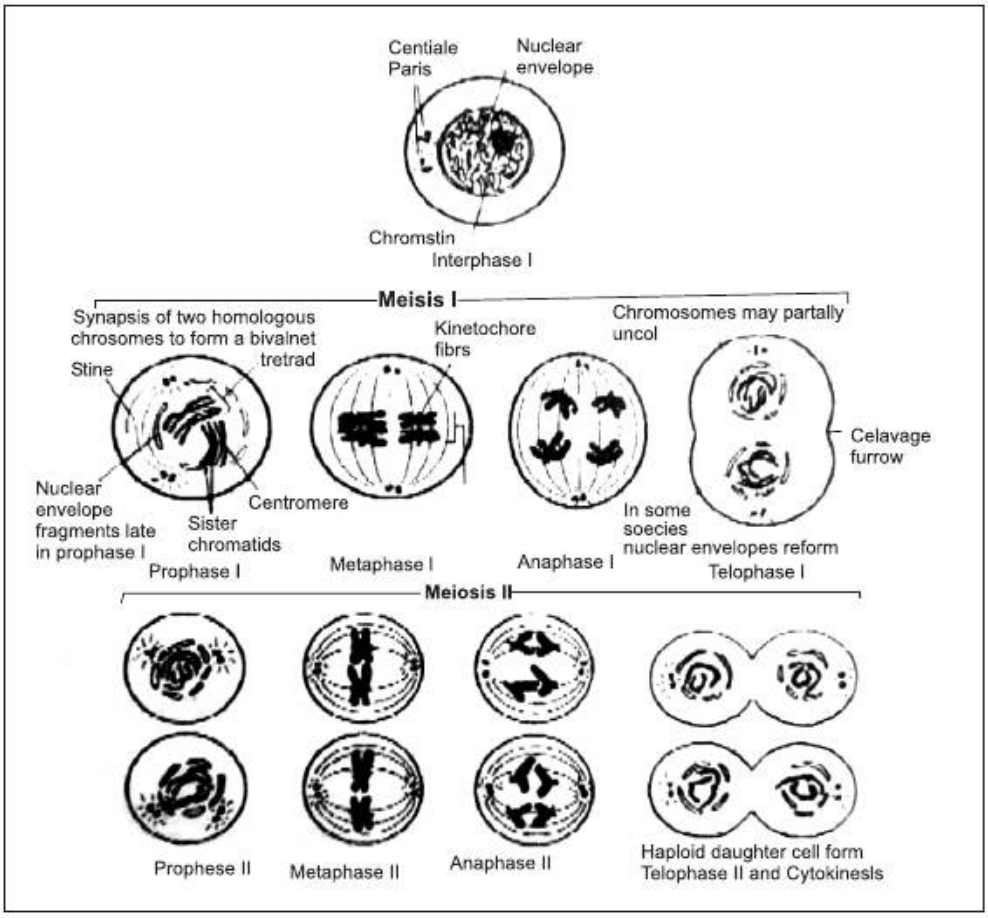

Fig. 2.7. Steps Involved in Meiosis

- **Telophase II**, the nuclear envelope reappears at each pole and cytokinesis occurs. The end result of meiosis is four haploid cells. Each cell contains half the number of chromosomes, and each chromosome consists of only one chromatid.

Meiosis ends with four haploid daughter cells, each with half the number of chromosomes (one chromosome from each homologous pair). These are gametes—that is, eggs and sperm. The fusing of an egg and sperm, fertilization (syngamy), gives rise to a diploid cell, the zygote. The single-celled zygote then divides by mitosis to produce a multicellular embryo fetus, and after nine months, a newborn infant. Note that one copy of each chromosome pair in the zygote originates from one parent, and the second copy from the other parent. Thus, a pair of homologous chromosomes in the diploid zygote represents both maternal and paternal heritage.

DNA Replication

During the S phase of interphase, a second chromatid is assembled. The second chromatid contains the exact same DNA found in the first chromatid. The copying process, called DNA replication, involves separating ("unzipping") the DNA molecule into two strands, each of which serves as a template to assemble a new, complementary strand. The result is two identical double-stranded molecules of DNA that consist of a single strand of old DNA (the template strand) and a single strand of new, replicated DNA (the complementary strand).

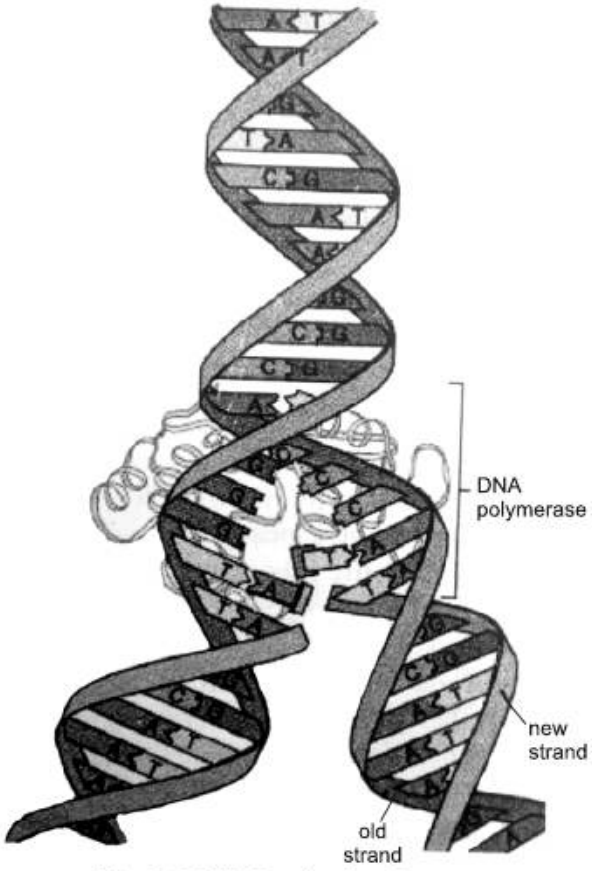

Fig. 2.8. DNA Replication Process

Two difficulties must be resolved during replication. First, DNA polymerase, the enzyme that regulates the attachment of new nucleotides to the growing complement strand of DNA, can perform this task in only one direction. The two strands that make up the double helix, however, are oriented in opposite directions (anti-parallel). On one strand, the DNA polymerase can operate continuously toward the replication fork as the DNA double helix is unzipped. The new DNA strand generated in this manner is called the leading complementary strand. Since the nucleotides of the second template strand are oriented in the opposite direction, DNA polymerase must operate away from the replication fork. As a result, replication of the second strand occurs in short segments. As the replication fork

advances, the DNA polymerase must repeatedly return to the replication fork to begin replication of short segments of DNA. The enzyme DNA ligase connects these short segments of DNA generating the lagging complementary strand.

The second difficulty that is resolved during replication is that DNA polymerase cannot itself initiate replication. Instead, the enzyme RNA primase initiates each replication using RNA (not DNA) nucleotides. After a short RNA nucleotide segment is generated, DNA polymerase takes over with DNA nucleotides.

The initial RNA nucleotides are later replaced with the appropriate DNA nucleotides (Fig. 2.8).

1. The enzyme helicase unwinds the DNA helix, producing Y-shaped replication fork.
2. RNA primase initiates DNA replication by producing short segments of RNA nucleotides called RNA primers. DNA polymerase attaches to the RNA primase and begins adding DNA nucleotides to the complement strand.
3. The leading complementary strand is assembled continuously as the double-helix of DNA uncoils.
4. The lagging complementary strand is assembled in short segments, which are subsequently joined by DNA ligase.
5. The RNA primers are replaced by DNA nucleotides.

Mutations

The replication process of DNA is extremely accurate. However, errors occur when nucleotide bases between DNA strands are occasionally paired incorrectly. In addition, errors in DNA molecules may arise as a result of exposure to radiation (such as ultraviolet or x-ray) or various reactive chemicals. When errors occur, repair mechanisms are available to make corrections.

If a DNA error is not repaired, it becomes a mutation. A mutation is any sequence of nucleotides in a DNA molecule that does not exactly match the original DNA molecule from which it was copied. Mutations include an incorrect nucleotide (substitution), a missing nucleotide (deletion), or an addition nucleotide not present in the original DNA molecule (insertion). When an insertion mutation occurs, it causes all subsequent nucleotides to be displaced one position, producing a frameshift mutation. Radiation or chemicals that cause mutations are called mutagens. Carcinogens are mutagens that activate uncontrolled cell growth (cancer).

Protein Synthesis

The DNA in chromosomes contains genetic instructions that regulate development, growth, and the metabolic activities of cells. The DNA instructions determine whether a cell will be that of a pea plant, a human, or some other organism, as well as establish specific characteristics of the cell in that organism. For example, the DNA in a cell may establish that it is a human cell. If during development, it becomes a cell in the iris of any eye, the DNA will direct other information appropriate for its location in the organism, such as the production of brown, blue or other pigmentation. DNA controls the cell in this manner because it contains codes for polypeptides. Many polypeptides are enzymes that regulate

chemical reactions and influence the resulting characteristics of the cell. Thus, from the molecular view point, traits are the end products of metabolic processes regulated by enzymes. A gene is defined as the DNA segment that codes for a particular enzyme or other polypeptide (one-gene-one-polypetide hypothesis).

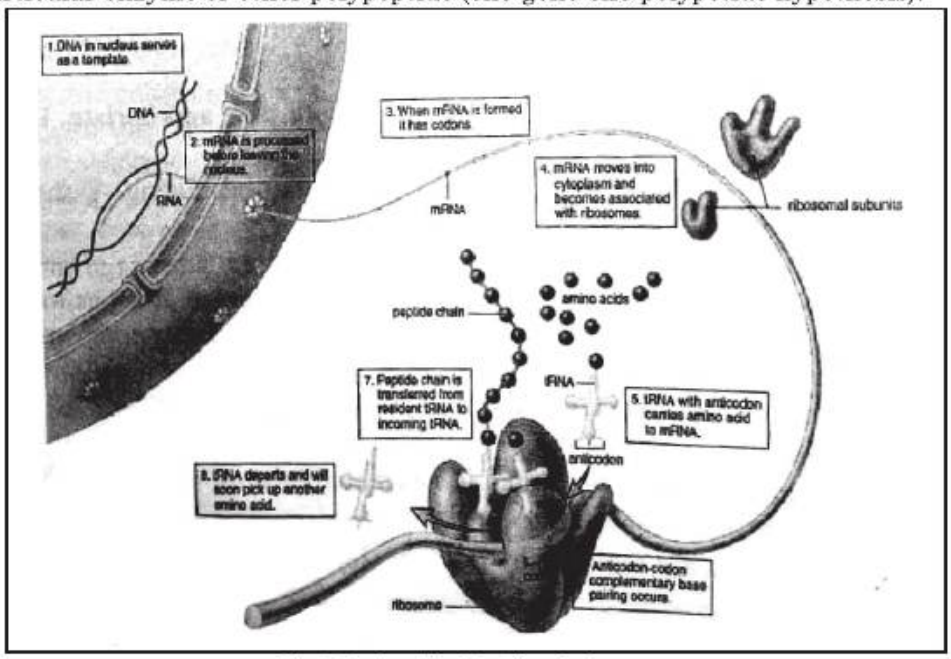

Fig. 2.9. Protein Synthesis Process

The process that describes how enzymes and other proteins are made from DNA is called protein synthesis. There are three steps in protein synthesis—transcription, RNA processing, and translation (fig. 2.9). In transcription, DNA molecules are used as a template to create RNA. After transcription, RNA processing modifies the RNA molecule with deletions and additions. In translation, the processed RNA molecules are used to assemble amino acids into a polypeptide.

There are three kinds of RNA molecules produced during transcription, as follows :

- **Messenger RNA** (mRNA) is a single strand of RNA that provides the template used for sequencing amino acids into a polypeptide. A triplet group of three adjacent nucleotides on the mRNA, called a codon, codes for one specific amino acid. Since there are 64 possible ways that four nucleotides can be arranged in triplet combinations ($4 \times 4 \times 4 = 64$), there are 64 possible codons. The genetic code is a table of information that provides "decoding" for each codon—that is, it identifies the amino acid specified by each of the possible 64 codon combinations. For example, the codon composed of the three nucleotides cytosine-guanine-adenine (CGA) codes for the amino acid arginine.
- **Transfer RNA** (tRNA) is a short RNA molecule (consisting of about 80 nucleotides) that is used for transporting amino acids to their proper places

on the mRNA template. Interactions among various parts of the tRNA molecule result in base-pairings between nucleotides, folding the tRNA in such a way that it forms a three-dimensional molecule. (In two dimensions, a tRNA resembles the three leaflets of a clover leaf). One end of the tRNA attaches to an amino acid. Another portion of the tRNA, specified by a triplet combination of nucleotides, is the anticodon. During translation, the anticodon of the tRNA base pairs with the codon of the mRNA.

- **Ribosomal RNA (rRNA)** molecules are the building blocks of ribosomes. The nucleolus is an assemblage of DNA actively being transcribed into rRNA. Within the nucleolus, various proteins imported from the cytosol are assembled with rRNA to form large and small ribosome subunits. Together, the two subunits form a ribosome, which coordinates the activities of the mRNA and tRNA during translation. Ribosomes have three binding sites—one for the mRNA, one for the tRNA that carries a growing polypeptide chain, and one for a second tRNA that delivers the next amino acid that will be inserted into the growing polypeptide chain.

Here are the details of transcription, RNA processing, and protein synthesis :

- During transcription, the RNA polymerase attaches to promoter regions on the DNA and beings to unzip the DNA into two strands.
- As the RNA polymerase unzips the DNA, it assembles new nucleotides using one strand of the DNA as a template. In contrast to the process of DNA replication, the new nucleotides are RNA nucleotides, and only one DNA strand is transcribed. Transcription continues until the RNA polymerase reaches a special sequence of nucleotides that serves as a termination point. The RNA polymerase and the newly created RNA molecule are released. This newly created RNA molecule may be mRNA, tRNA, or rRNA (depending on which DNA segment is transcribed). During RNA processing, newly created mRNA molecules undergo two kinds of alterations. In the first modification, noncoding intervening sequences called introns are removed, leaving only exons, sequences that express a code for a polypeptide. A second modification adds two special sequences—a 5-inch cap to one end of the mRNA and a poly-A tail to the other end.
- The mRNA, tRNA, and ribosomal subunits are transported across the nuclear envelope and into the cytoplasm. In the cytoplasm, amino acids attach to one end of the tRNAs.
- Translation begins when the small and large ribosomal subunits attach to one end of the mRNA. Also, a tRNA (with anticodon UAC) carrying the amino acid methonine attaches to the mRNA (at the "start" codon AUG) within the ribosome. A second tRNA, also bearing an amino acid, arrives and fills a second tRNA position. The codon on the mRNA determines which tRNA (and thus, which amino acid) fills the second position.
- The amino acid of the first tRNA attaches to the amino acid of the second tRNA, forming a pair of amino acids. Then, the first tRNA is released. The ribosome moves over one codon position, thereby putting the second tRNA in the first position and vacating the second position.
- A new tRNA (with its amino acid) fills the vacant position. Now, the two amino acids being held by the tRNA in the first position are transferred to

the amino acid of the newly arrived tRNA, forming a polypetide chain of three amino acids. Again, the tRNA in the first position is released, the ribosome moves over one codon position, and the second tRNA position is vacant.

- The process continues, as new tRNAs bring more amino acids. As each new tRNA arrives, the polypeptide chain is elongated by one new amino acid, growing in sequence and length as dictated by the condons on the mRNA.
- Eventually, a "stop" codon is encountered, and the ribsome subunits and polypeptide are released.

Once the polypeptide is released, interactions among the amino acids give it its special three-dimensional shape. Subsequent processing by the endoplasmic reticulum or a Golgi body may make final modifications before the protein functions as a structural element or an enzyme.

High Yield Terms to Learn

- **Cell Biology :** The study of the activities, functions, properties, and structures of cells.
- **Molecular Biology :** The branch of biology that studies the structure and activity of macromolecules essential to life (and especially with their genetic role).
- **Glycobiology :** The study of molecules that contain carbohydrates, their structure and function, and the roles they play in biology.
- **Mitosis :** The ordinary type of nuclear division preceded by faithful replications of chromosome.
- **Meiosis :** The process which, through two successive cell division leads to formation of mature gametes.
- **Apoptosis :** A natural process of self-destruction in certain cells that is determined by the genes and can be initiated by a stimulus or by removal of a repressor agent. Also called *programmed cell death*.

EXERCISE

Fill in the Blanks

1. ..... discovered the cell.
2. Anaphase in Mitosis have ..... copy of DNA.
3. ..... conclude the cell division in mitosis.
4. ..... means cell eating?
5. Exocytosis means transport of ions ..... .
6. Endocytosis means transport of ions ..... .
7. Microtubules are arranged in ..... array.
8. ..... chromosomes are present after Meiosis.
9. ..... is start codon.
10. ..... is stop codon.

One Word

1. tRNA stands for?

2. ATP means?
3. rRNA stands for?
4. mRNA stands for?
5. DNA means?
6. Is known as powerhouse of cell?
7. Is example of active transport?
8. What is homologous pair?
9. Cell drinking is known as?
10. How many phases are their in Meiosis?

Very Short Type Questions

1. Examples of Passive Transport?
2. What is osmosis?
3. What do you mean by Tonicity?
4. Isotonic means?
5. Why Mitosis is important?

Short Answer Type Questions

1. What is the role of mRNA?
2. Write a note on tRNA?
3. Enlight the role of rRNA in Protein synthesis?
4. What is Apoptosis?
5. Write a note on Mutation?
6. What is the importance of Mitosis?
7. Why Meiosis is necessary in cell?
8. Write a note on Osmosis?
9. What is Tonicity?
10. Write a note on Endocytosis?
11. Write a note on plasma membrane permeability?
12. Write a note on nucleus of cell?

Long Answer Type Questions

1. Enlight the cell structure?
2. What is passive transport process in cell?
3. What is active transport process in cell?
4. Write a note on cell division?
5. What is mitosis process in cell division?
6. Explain whole process of meiosis?
7. Enlight the process of DNA replication?
8. What is mutation?
9. Explain the process of Protein Synthesis?

❖ ❖ ❖