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Ministry of Science and Higher Education- Ethiopia

Module for General Biology (Biol. 1012)

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Preface

The primary goal of this module is to provide the basic information about general biology. Biology is an introductory college text that covers the concepts and principles from the structure and function of the cell to the organization of the biosphere. It draws up on the entire world of living things to bring out an evolutionary theme that is introduced from the start.

The writing style and clarity of this module make it appropriate for use by liberal students; it gives an opportunity for the reader participate in scientific analysis, as notable practical's/ investigations are mentioned, and significant experiments and laboratory works are fully explained. These all are also followed by self-testing questions, which encourage students to use scientific methodology in order to think critically.

Team members

Table of Contents

Module Objectives

At the end of the course, the student will be able to:

- ✓ Explain the scope of biology and molecular basis of life
- ✓ Describe life activities from the cellular point of view
- ✓ Manipulate basic biological tool, record data and draw conclusions
- ✓ Develop scientific attitude, skill and conduct biological experiments using scientific procedures
- ✓ Outline basic processes of energy transduction and synthesis of intermediate or final products in living cells
- ✓ Understand the basic concepts of genetics and inheritance
- ✓ Understand the concepts of infection and immunity
- ✓ Classify organisms based on their cellular organization and complexity
- ✓ Explain components, processes and interrelationships within a given ecosystem
- ✓ Know the general features of invertebrate and vertebrate animals
- ✓ Appreciate the practical uses of biological knowledge and its application in the wider society

Acknowledgements

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Unit

1. Introduction

Dear learner! Welcome to this module which deals about the course, General Biology (Biol. 1012). This module chapter is primarily intended for natural science students to familiarize with basic concepts of biological science, the nature and origin of life, scientific methods and the subject matter of biology. I hope you will find it interesting!

Learning Objectives: After completing this chapter, you will be expected to:

- ✓ define the term biology
- ✓ explain scientific methods
- ✓ know the origin and the nature of life

1.1 The meaning and scope of biology

Self-test:-

1. Do you know the meaning and the scope of Biology? Discuss it

2. Explain the origin and the nature of life

3. What are the branches of biology?

Biological Sciences is the study of life and living organisms. It is also called as “Biology”. The Greek word ‘bio’ means life and ‘logos’ means study of. In the late 1700s Pierre-Antoine de Monet and Jean-Baptiste de Lamarck coined the term biology. Earlier study of living things was restricted to the pure Science like Botany and Zoology that together comprise the Biology, but as the time passed new branches evolved. New technologies developed in pure subjects as well as in applied fields, which gave rise to a very broad concept of science called Biological Sciences. Biological Sciences is an extensive study covering the minute workings of chemical substances inside living cells to the broad scale concepts of ecosystems and global environmental changes.

It is also concerned with the physical characteristics and behaviors of organisms living today and long ago. How they came into existence and what relation they possess with each other and their environments? Intimate study of details of the human brain, the composition of our genes, and even the functioning of our reproductive system are dealt in Biological sciences.

Therefore, Biology is the science of Living Things. That is why Biology is sometimes known as Life Science.

The life sciences can be defined as “a systematic study of living beings or study of nature”. Teaching of life Science basically deals with providing information about the latest developments in the field of Biological sciences all over the world.

1.2 The origin and nature of life

Self-test:-

1. Explain the origin and the nature of life

2. What are the Scientific Methods?

One of the biggest and most important of emergent phenomena is that of the origin or emergence of life. The mystery of life's origin is still a big debating issue in science. The question “what is life?” is so hard to answer; we really want to know much more than what it is, we want to know why it is, “we are really asking, in physical terms, why a specific material system is an organism and not something else”. To answer this why question we need to understand how life might have originated. There are a number of theories about the origin of life. The next few sections give emphasis on these different theories about the origin of life.

The evolution of life on earth has involved the following sequence of events. The first living things to appear were the simplest creatures, single-celled organisms. From these came more complex, multi-cellular organisms. Becoming more complex meant more than just an increase in cell number but more cells showed cellular specialization, where certain cells within the multi-cellular organism carried out specific tasks. Millions, even billions of years of changes of organisms led to the living things we now call plants and animals.

Since this basic sequence of events is in accord with that agreed upon by most geologists, paleontologists, biologists, and even theologians, one might conclude that Moses, Aristotle, and Darwin were all keen observers and naturalists who were able to logically assess the most probable creation story. Scientists generally concur that the time from the formation of our solar system until now has been on the order of some 4.5 billion years. Those who believe the world as we know it was created in six days are often called creationists. Their method of inquiry is based on the belief that the Bible is to be accepted as a completely accurate accounting of all about which it speaks. Scientists**,** on the other hand, utilize what they call the scientific method**,** which allows them to test hypotheses and theories and to develop concepts and ideas.

Summary of Theories on Origin of life

Several attempts have been made from time to time to explain the origin of life on earth. As a result, there are several theories which offer their own explanation on the possible mechanism of origin of life. Following are some of them:

1. Theory of Special Creation: according to this theory, all the different forms of life that occur today on planet earth have been created by God, the almighty.

Theory of Spontaneous Generation: this theory assumed that living organisms could arise suddenly and spontaneously from any kind of non-living matter. One of the firm believers in spontaneous generation was Aristotle, the Greek philosopher (384-322 BC).

2.Theory of Catastrophism: It is simply a modification of the theory of Special Creation. It states that there have been several creations of life by God, each preceded by a catastrophe resulting from some kind of geological disturbance. According to this theory, since each catastrophe completely destroyed the existing life, each new creation consisted of life form different from that of previous ones.

3. Cosmozoic Theory (Theory of Panspermia): according to this theory, life has reached this planet Earth from other heavenly bodies such as meteorites, in the form of highly resistance spores of some organisms. This idea was proposed by Richter in 1865 and supported by Arrhenius (1908) and other contemporary scientists. The theory did not gain any support. This theory lacks evidence, hence it was discarded.

4. Theory of Chemical Evolution: this theory is also known as Materialistic Theory or Physico-chemical Theory. According this theory, Origin of life on earth is the result of a slow and gradual process of chemical evolution that probably occurred about 3.8 billion years ago. This theory was proposed independently by two scientists - A.I.Oparin, a Russian scientist in 1923 and J.B.S Haldane, an English scientist, in 1928.

Nature and characteristics of life

Life is defined as a "condition" that distinguishes animals and plants from inorganic materials and dead organisms.

- Life is comprised of processes and is a maintained state.

- The most sophisticated form of life is man as a result of this we focuses upon the nature of the life and death of man.

Man demonstrates three lives or aspects of life: Life of the body (physical), life of the mind and life of the spirit.

- **Physical life** is basic existence
- **Mind contributes effectiveness and scope**
- **Spiritual entity contributes maximum living**.

Physiology: The existence of life physical is demonstrated by the presence of functions.

Living tissues and organisms exhibit:

Irritability: the ability to be excited or detect stimuli and to respond thereto

Growth and reproduction: this consists of the power of multiplication and duplication, regeneration and differentiation

Adaptability: permitting both change and maintenance of balances (homeostasis)

Finally and most characteristic of all is **Metabolism**: the transformation of energy and the use of materials. These properties, however, can be retained for a while by tissues after death of the organism so there is another mystery of life which we understand only in part.

Excretion: *excretion and osmoregulation regulation are two important homeostatic processes occurring in living cells, helping them to maintain a constant internal environment, or steady state. Excretion is the removal from the cell of waste products of metabolism. In plant cells the major excretory products are oxygen from photosynthesis and carbon dioxide from cell respiration.*

1.3 Scientific methods

Self-test:-

1. *Write dawn the main steps of the scientific methods in sequence?*
2. *You observe that a room appears dark, and you wonder why the room is dark? In an attempt to find explanations to this curiosity, what are the possible hypotheses that come in your mind to discover the truth?*
3. *What are the major common properties of living things?*

The **scientific method** is a process for experimentation that is used to explore observations and answer questions. It is an empirical method of acquiring knowledge. It is also the technique used in the construction and testing of a scientific hypothesis.

The scientific method has five basic steps, plus one feedback step:

- ✓ Make an observation.
- ✓ Ask a question.
- ✓ Form a **hypothesis**, or testable explanation.
- ✓ Make a prediction based on the hypothesis.
- ✓ Test the prediction.
- ✓ **Iterate**: use the results to make new hypotheses or predictions.

Observation - *Quantitative and qualitative measurements of the world.*

Inference - *Deriving new knowledge based upon old knowledge.*

Hypotheses *–A suggested explanation.*

Rejected Hypothesis - *An explanation that has been ruled out through experimentation.*

Accepted Hypothesis - *An explanation that has not been ruled out through excessive experimentation and makes verifiable predictions that are true.*

Experiment - *A test that is used to rule out a hypothesis or validate something already known.*

Scientific Method - *The process of scientific investigation.*

Theory - *A widely accepted hypothesis that stands the test of time. Often tested, and usually never rejected.*

The scientific method is based primarily on the testing of hypotheses by experimentation. This involves a **control**, *or subject that does not undergo the process in question. A scientist will also seek to limit* **variable***s to one or another very small number, single or minimum number of variables. The procedure is to form a hypothesis or prediction about what you believe or expect to see and then do everything you can to violate that, or falsify the hypotheses. Although this may seem unintuitive, the process serves to establish more firmly what is and what is not true.*

Summary of the scientific method
Step 1: Observe behavior or other phenomena
Step 2: Form a tentative answer or explanation (a hypothesis (guess a reason)
Step 3: Use your hypothesis to generate a testable prediction
Step 4: Make systematic, planned observations (data collection)
Step 5: Results and Discussion Use the observations to evaluate (support, refute, or refine) the original hypothesis
Step 6: Conclusion
Step 7: Recommendation

Chapter review questions

1. List dawn all the steps used in scientific methods
2. Propose a hypothesis in an attempt to find explanations for this curiosity
3. Explain the differences between control and variable group
4. List down the characteristics common to all living things
5. What is a controlled experiment? Why is it essential to have a control group in scientific experiment?

Unit

2. Biological Molecules

Biological molecules are often referred to as the molecules of life (bio-molecules) that are basically found in a living cell and categorized as organic and inorganic molecules in general. Each member of the groups is vital for every single organism on Earth. The organic biomolecules are proteins, carbohydrates, lipids and nucleic acids. Without any of these four molecules, a cell and organism would not be able to live. They are important either structurally or functionally for cells and, in most cases, they are important in both ways. the most commonly known inorganic molecules are water and minerals, which are still important for the normal functioning of the cell.

Learning Objectives: After completing this chapter you will be expected to:

- ✓ define the term biomolecules
- ✓ describe list of organic and inorganic molecules and their biological importance
- ✓ identify the basic structures of biomolecules
- ✓ explain the precursors of each macromolecules with their respective polymerization process
- ✓ state the physical and chemical nature of water and their relevance to the existence of life

1.4 Carbohydrates

Self-test:

1. What are the elemental compositions of carbohydrates?

2. Why cells rely on carbohydrates as a major source of energy compared to other biomolecules?

3. What are the additional importance's of carbohydrates besides their role as energy source?

A carbohydrate molecule is made of atoms of carbon, hydrogen and oxygen. They are an important source of energy and they also provide structural support for cells and help with communication between cells (cell-cell recognition). They are found in the form of either a sugar or many sugars linked together, called **saccharides**. Based on the number sugar units they contain, they are categorized into three, as follows.

- A single sugar molecule containing carbohydrate is known as a **monosaccharides**, while two and many having are regarded as disaccharides **and polysaccharides, respectively.**
- Each of the sugar molecules are bonded together through the glycosidic linkage/s. The three different types of carbohydrates are all important for different reasons
- **Carbohydrates** are polyhydroxy aldehydes or ketones, or substances that yield these compounds on hydrolysis. Example: Glucose is an aldehyde while fructose is a ketone.

Monosaccharides - simple sugars with multiple OH groups. Based on number of carbons (3, 4, 5, 6), a monosaccharide is a triose, tetrose, pentose or hexose.

Disaccharides - 2 monosaccharides covalently linked

Oligosaccharides - a few monosaccharides covalently linked.

Polysaccharides - polymers consisting of chains of monosaccharide or disaccharide

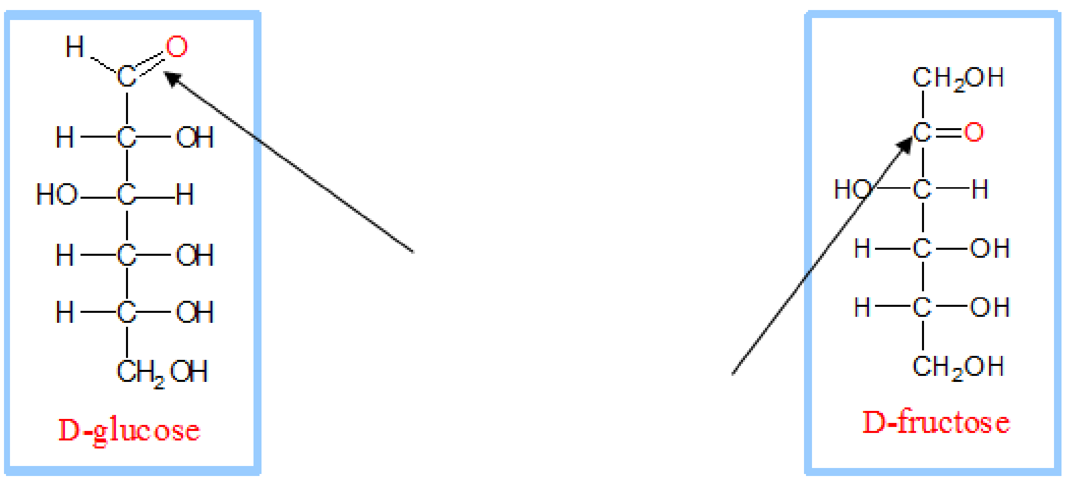


Fig: 2.1. Structures of monosaccharides (glucose and fructose)

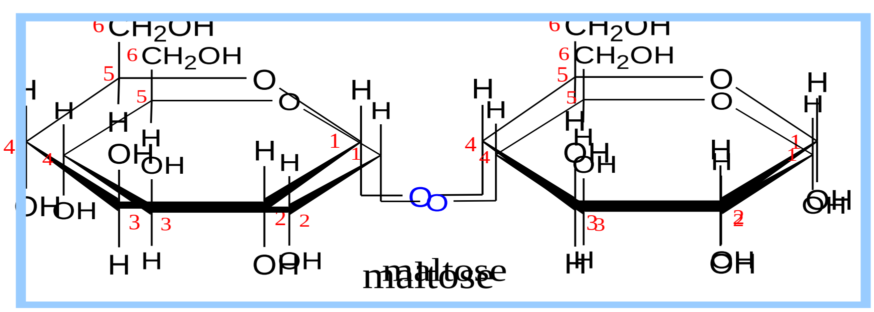


Fig: 2.2. A structure of maltose (disaccharide)

Monosaccharides

Monosaccharides containing the aldehyde group are classified as **aldoses**, and those with a ketone group are classified as **ketoses**. Aldoses are reducing sugars; ketoses are non-reducing sugars. This is important in understanding the reaction of sugars with Benedict's reagent. However, in water pentoses and hexoses exist mainly in the cyclic form, and it is in this form that they combine to form larger saccharide molecules.

Glucose

Glucose is the most important carbohydrate fuel in human cells. Its concentration in the blood is about 1 gdm^{-3}. The small size and solubility in water of glucose molecules allows them to pass through the cell membrane into the cell. Energy is released when the molecules are metabolized.

Two glucose molecules react to form the dissacharide **maltose**. **Starch** and **cellulose** are polysaccharides made of glucose units.

Galactose

Galactose molecules look very similar to glucose molecules. They can also exist in α and β forms. Galactose reacts with glucose to make the dissacharide **lactose**. However, glucose and galactose cannot be easily converted into one another. Galactose cannot play the same part in respiration as glucose. This comparison of glucose and galactose shows why the precise arrangement of atoms in a molecule (shown by the displayed formula) is so important.

Fructose

Fructose, glucose and galactose are all hexoses. However, whereas glucose and galactose are aldoses (reducing sugars), fructose is a ketose (a non-reducing sugar). It also has a five-atom ring rather than a six-atom ring. Fructose reacts with glucose to make the dissacharide **sucrose**.

Ribose and deoxyribose

Ribose and deoxyribose are pentoses. The ribose unit forms part of a **nucleotide** of **RNA**. The deoxyribose unit forms part of the nucleotide of **DNA**.

Disaccharides

Monosaccharides are rare in nature. Most sugars found in nature are disaccharides. These form when two monosaccharides react. Disaccharides are soluble in water, but they are too big to pass through the cell membrane by diffusion. They are broken down in the small intestine during digestion to give the smaller monosaccharides that pass into the blood and through cell membranes into cells.

$$C_{12}H_{22}O_{11} + H_2O \rightarrow C_6H_{12}O_6 + C_6H_{12}O_6$$

This is a **hydrolysis reaction** and is the reverse of a condensation reaction and it releases energy.

A **condensation reaction** takes place by releasing water. This process requires energy. A **glycosidic bond** forms and holds the two monosaccharide units together. The three most important disaccharides are **sucrose**, **lactose** and **maltose**. They are formed from the a forms of the appropriate monosaccharides. Sucrose is a non-reducing sugar. Lactose and maltose are reducing sugars.

Monosaccharides are used very quickly by cells. However, a cell may not need all the energy immediately and it may need to store it. Monosaccharides are converted into disaccharides in the cell by condensation reactions. Further condensation reactions result in the formation of polysaccharides. These are giant molecules which, importantly, are too big to escape from the cell. These are broken down by hydrolysis into monosaccharides when energy is needed by the cell.

Polysaccharides

Monosaccharides can undergo a series of condensation reactions, adding one unit after another to the chain until very large molecules (polysaccharides) are formed. This is called **condensation polymerisation**, and the building blocks are called **monomers**. The properties of a polysaccharide molecule depend on:

- Its length (though they are usually very long)

- The extent of any branching (addition of units to the side of the chain rather than one of its ends)
- Any folding which results in a more compact molecule
- Whether the chain is 'straight' or 'coiled'

Starch

Starch is often produced in plants as a way of storing energy. It exists in two forms: **amylose** and **amylopectin**. Both are made from α-glucose. Amylose is an unbranched polymer of α-glucose. The molecules coil into a helical structure. It forms a colloidal suspension in hot water. Amylopectin is a branched polymer of α-glucose. It is completely insoluble in water.

Glycogen

Glycogen is amylopectin with very short distances between the branching side-chains. Starch from plants is hydrolysed in the body to produce glucose. Glucose passes into the cell and is used in metabolism. Inside the cell, glucose can be polymerised to make glycogen which acts as a carbohydrate energy store.

Cellulose

Cellulose is a third polymer made from glucose. But this time it's made from β-glucose molecules and the polymer molecules are 'straight'. Cellulose serves a very different purpose in nature to starch and glycogen. It makes up the cell walls in plant cells. These are much tougher than cell membranes. This toughness is due to the arrangement of glucose units in the polymer chain and the **hydrogen-bonding** between neighboring chains. Cellulose is not hydrolysed easily and, therefore, cannot be digested so it is not a source of energy for humans. The stomachs of Herbivores contain a specific enzyme called cellulase which enables them to digest cellulose.

Summary of carbohydrates

- The most abundant organic molecules in nature
- Are polyhydroxy aldehydes or ketones, or substances that yield these compounds on hydrolysis
- Provide a significant fraction of the energy in the diet of most organisms
- Important source of energy for cells
- Can act as a storage form of energy
- Can be structural components of many organisms
- Can be cell-membrane components mediating intercellular communication
- Can be cell-surface antigens
- Can be part of the body's extracellular ground substance
- Can be associated with proteins and lipids
- Part of RNA, DNA, and several coenzymes (NAD+, NADP+, FAD, CoA)

1.5 Lipids

Self-test:
1. What are lipids?
2. What is the difference between saturated and unsaturated?
3. What are the physiological and structural roles of lipids for life forms?

Lipids are a highly variable group of molecules that include fats, oils, waxes and some steroids. They are esters of fatty acids and alcohol (glycerol or chains of alcohols). Fatty acids are made mostly from chains of carbon and hydrogen and they bond to a range of other types of atoms to form many different lipids. The primary function of lipids is to store energy.

A lipid called a triglyceride is a fat if it is solid at room temperature and oil if it is liquid at room temperature. In addition, triglycerides are stored in the fat cells, also called adipocytes or lipocytes, and are responsible in storing fats and lipids which will facilitate energy store in animals' body. Fat cells are categorized in white fat cells and brown fat cells. The different is made from their ways of storing lipids. White fat cells store one large lipid drop while brown fat cells store smaller and multiple droplets of lipids spreading in the whole body of the cell. Various types of lipids occur in the human body, namely 1) triacylglycerol, 2) cholesterol, and 3) polar lipids, which include phospholipids, glycolipids and sphingolipids. Plant leaves are coated with lipids called waxes to prevent water loss, and the honeycomb in a beehive is made of beeswax.

The basic structure of a lipid includes fatty acid tails as shown in **Figure 2.3.** Each tail is a chain of carbon atoms bonded to hydrogen and other carbon atoms by single or double bonds. Lipids that have tail chains with only single bonds between the carbon atoms are called saturated fats because no more hydrogens can bond to the tail. Lipids that have at least one double bond between carbon atoms in the tail chain can accommodate at least one more hydrogen and are called unsaturated fats. Fats with more than one double bond in the tail are called **polyunsaturated fats**.

Properties of lipids

- Insoluble in water
- Longer chains
  - ✓ More hydrophobic, less soluble
- Double bonds increase solubility
- Melting points:
  - ✓ Depend on chain length and saturation
  - ✓ Double bonds lead acyl chain disorder and low melting temperatures
  - ✓ Unsaturated fatty acids are solid at room temperature.

Importance of lipids

- ➢ As the main component of cell membranes (phospholipids)
- ➢ Insulation of heat and water,
- ➢ Storing energy, protection and cellular communication.

Activity

1. What are the elemental compositions of lipids?

2. Why lipids act as major source of energy?

3. What are the major classes of lipids?

4. Jot down the importance of cholesterol?

1.6 Proteins

Self-test:
1. Comment on the following statements (answer by saying true or false for each statement and then elaborate)
- *a) All proteins are enzymes*
- *b) Enzymes initiate a chemical reaction*
- *c) Chemical reactions cannot take place in the body without enzymes*

2. What are the elemental compositions of proteins?
3. What are the physiological and structural roles of proteins?
4. Compare protein with nucleic acid
5. How is the primary structure of a protein determined?

A **protein** is a compound made of small carbon compounds called amino acids. **Amino acids** are small compounds that are made of carbon, nitrogen, oxygen, hydrogen, and sometimes sulfur. All amino acids share the same general structure.

Amino acids have a central carbon atom like the one shown in **Fig. 2.3.** Recall that carbon can form four covalent bonds. One of those bonds is with hydrogen. The other three bonds are with an amino group (–NH2), a carboxyl group (–COOH), and a variable group (–R). The variable group makes each amino acid different. There are 20 different variable groups, and proteins are made of different combinations of all 20 different amino acids. Several covalent bonds called peptide bonds join amino acids together to form proteins, which are also shown in **Fig. 2.3.** A peptide forms between the amino group of one amino acid and the carboxyl group of another.

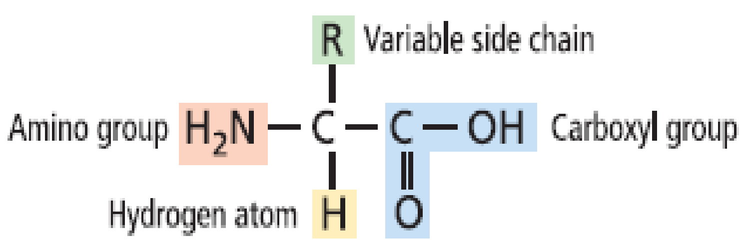


Fig: 2.3. Basic structure of amino acid

Based on the variable groups contained in the different amino acids, proteins can have up to four levels of structure. The number of amino acids in a chain and the order in which the amino acids are joined define the protein's primary structure. After an amino acid chain is formed, it folds into a unique three-dimensional shape, which is the protein's secondary structure. A protein might contain many helices, pleats, and folds. The tertiary structure of many proteins is globular, such as the hemoglobin protein**,** but some proteins form long fibers. Some proteins form a fourth level of structure by combining with other proteins.

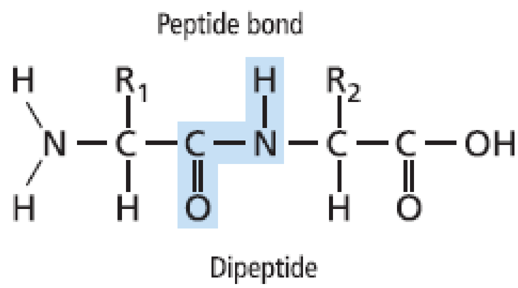


Fig: 2.4. Peptide bond

Proteins make up about 15 percent of your total body mass and are involved in nearly every function of your body. For example, your muscles, skin, and hair all are made of proteins. Your cells contain about 10,000 different proteins that provide structural support, transport substances inside the cell and between cells, communicate signals within the cell and between cells, speed up chemical reactions, and control cell growth.

1.7 Nucleic acids

Self-test:
1. What is the role of nucleic acid?
2. What are the molecular compositions of nucleotides?
3. Describe briefly the differences between DNA & RNA?

Nucleic acids are complex macromolecules that store and transmit genetic information. Nucleic acids are made of smaller repeating subunits called **nucleotides.** Nucleotides are composed of carbon, nitrogen, oxygen, phosphorus, and hydrogen atoms. There are six major nucleotides, all of which have three units a phosphate, a nitrogenous base, and a ribose sugar, as shown in Fig. 2.5

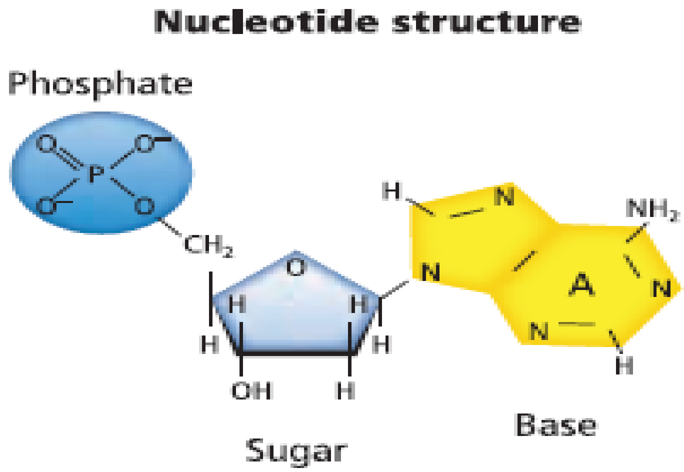


Fig. 2.5. Basic structure of nucleotide

There are two types of nucleic acids in living organisms: deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). In nucleic acids such as DNA and RNA, the sugar of one nucleotide bonds to the phosphate of another nucleotide. There are five different bases found in nucleotide subunits that make up DNA and RNA, Adenine, Cytosine, Guanine, Thymine and Uracil. Each of these nitrogenous base that sticks out from the chain is available for hydrogen bonding with other bases in other nucleic acids.

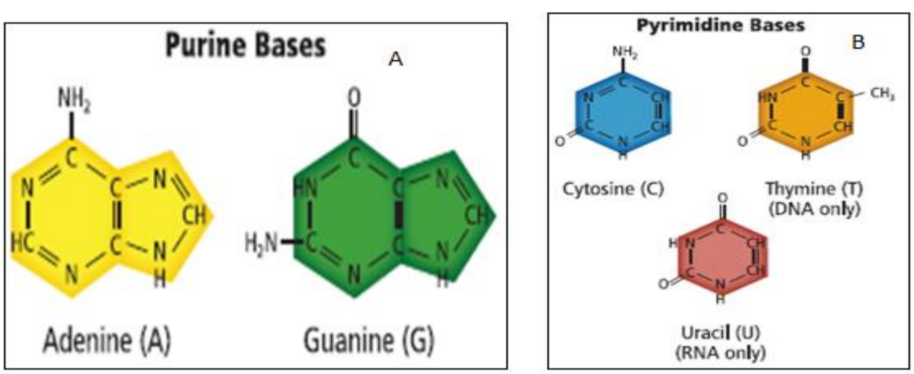


Fig: 2.6. Nitrogenous bases

A nucleotide with three phosphate groups is adenosine triphosphate (ATP). ATP is a storehouse of chemical energy that can be used by cells in a variety of reactions. It releases energy when the bond between the second and third phosphate group is broken.

1.8 Vitamins

Self-test:
1. What are vitamins?
2. What are the roles of vitamins in maintaining homeostasis?
3. What are the water soluble and fat soluble vitamins?

Vitamins are organic compounds that are needed in small amounts for metabolic activities. Many vitamins help enzymes function well. Vitamin D is made by cells in your skin. Some B vitamins and vitamin K are produced by bacteria living in the large intestine. Sufficient quantities of most vitamins cannot be made by the body, but a well-balanced diet can provide the vitamins that are needed. Some vitamins that are fat-soluble can be stored in small quantities in the liver and fatty tissues of the body. Other vitamins are water-soluble and cannot be stored in the body. Foods providing an adequate level of these vitamins should be included in a person's diet on a regular basis.

1.9 Water

Self-test:
What are the physical and chemical properties of water, and their roles in maintaining homeostasis?

Water molecules are formed by covalent bonds that link two hydrogen (H) atoms to one oxygen (O) atom, and each water molecule has the same structure. It is one of the most plentiful and essential of compounds, which is a tasteless and odorless, existing in gaseous, liquid, and solid states. It has the important ability to dissolve and as a media for transportation of many other substances. In reality, the versatility of water as a solvent is essential to living organisms, as well.

Water molecules have an unequal distribution of charges and are called **polar molecules**, meaning that they have oppositely charged regions.

Activity (Think Scientifically)

1. *What would have happened to the living things if the color of water was black or red?*
2. *Even if water exists on other planets but it couldn't support life and what is the mystery behind this for the existence of life on earth?*

1.10 Minerals

Self-test:
1. What are minerals?
2. What are the roles of minerals in maintaining homeostasis?

Minerals are inorganic compounds used by the body as building material, and they are involved with metabolic functions. For example, the mineral iron is needed to make hemoglobin and it binds to hemoglobin in red blood cells and is delivered to body cells as blood circulates in the body. Calcium, and other minerals, is an important component of bones and is involved with muscle and nerve functions and they serve as **cofactors for enzymes**. Magnesium is an important component of the green pigment, **chlorophyll**, involved in photosynthesis.

Activity
1. Explain why raw edible oil is added on dishes of raw vegetables before consumption?

Summary of unit two

- ✓ *Carbon compounds are the basic building blocks of living organisms.*
- ✓ *Biological macromolecules are formed by joining of small carbon compounds into polymers.*
- ✓ *There are four types of biological macromolecules; carbohydrates, proteins, lipids and nucleic acids*
- ✓ *Monosaccharides undergo condensation to form disaccharides and poly saccharides through the glycosidic linkages*
- ✓ *Peptide bonds join amino acids in proteins.*
- ✓ *Lipids are esters of fatty acids and alcohols*
- ✓ *Chains of nucleotides form nucleic acids.*

Chapter Review Questions

1. Explain if an unknown substance found on a meteorite is determined to contain no trace of carbon, can scientists conclude that there is life at the meteorite's origin?
2. List and compare the four types of biological macromolecules.
3. Identify the components of carbohydrates and proteins.
4. Discuss the importance of amino acid order to a protein’s function.
5. Given the large number of proteins in the body, explain why the shape of an enzyme is important to its function.
6. Compare and contrast the functions of carbohydrates, lipids, proteins, and nucleic acids.
7. State why the polarity of water molecules makes water a good solvent.
8. Given the large number of proteins in the body, explain why the shape of an enzyme is important to its function?

Unit
3. The cellular basis of life

Learning Objectives: Upon successful completion of this unit, you should be able to:

- ✓ *Explain the cell theory*
- ✓ *Compare and contrast prokaryotic and eukaryotic cells*
- ✓ *Identify the different types of organelles, their structure and functions*
- ✓ *Tell mechanisms of cellular transport*
- ✓ *Justify why a cell membrane selective*

Self-Test:
1. State the cellular basis of life and cell theory
2. Identify the different types of organelles, their structure and functions
3. Why is homogenization important in cell study?

In the late 1600s, an English scientist named Robert Hook was the first to observe plant cells with a crude microscope. Then, almost a century and a half later, in the 1830's two German scientists proposed that all living things are composed of cells (their names were Mathias Schleiden and Theodore Schwann). A German pathologist, Rudolph Virchow extended this idea by contending that cells arise only from other cells.

3.1 The cell theory
A cell is the basic structural and functional unit of living organisms. The activity of an organism depends on both the individual and the collective activities of its cells. According to the principle of complementarity of structure and function, the biochemical activities of cells are dictated by their shapes or forms, and by the relative number of their specific sub-cellular structures. All cells arise from pre-existing cells (continuity of life from one generation to another has a cellular basis).

A typical eukaryotic cell has 3 major parts:

- ❖ The **plasma membrane**: the outer boundary of the cell.
- ❖ The **cytoplasm**: the intracellular fluid packed with organelles, small structures that perform specific cell functions.

❖ The **nucleus**: an organelle that controls cellular activities. Typically the nucleus resides near the cells center.

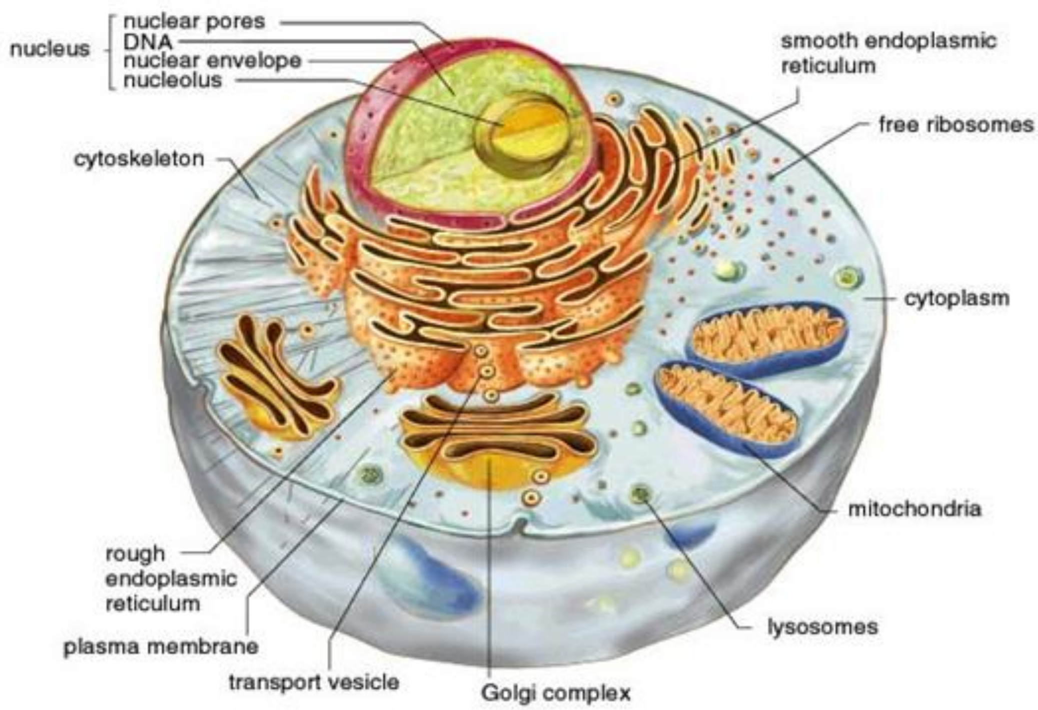


Fig: 3.1. Generalized animal cell

3.1.1 Cell organelles

An organelle is a specialized subunit within a cell that has a specific function. In eukaryotes an organelle is a membrane bound structure found within a cell. Just like cells have membranes to hold everything in, these mini-organs are also bound in a double layer of phospholipids to insulate their little compartments within the larger cells. Prokaryotes are cells that do not have membrane bound organelles. You can think of organelles as smaller rooms within the factory, with specialized conditions to help these rooms carry out their specific task (like a break room stocked with goodies or a research room with cool gadgets and a special air filter). These organelles are found in the cytoplasm, a viscous liquid found within the cell membrane that houses the organelles and is the location of most of the action happening in a cell.

There are two kinds of cell organelles on the basis membrane covering, membranous and non-membranous organelles. Endoplasmic reticulum (Rough and Smooth), Golgi bodies, mitochondria, chloroplasts, nucleus, lysosomes, peroxisomes and vacuoles are membranous whereas, non-membrane bound cell organelles are ribosomes (70*s* and 80*s*), centrosomes, cilia and flagella, microtubules, basal bodies and microfilaments.

3.1.2 Structure and function of organelles

The nucleus: This is distinctly oval or spherically shaped largest central structure surrounded by a double-layered membrane. In the nucleus, DNA directs protein synthesis and serves as a genetic blueprint during cell replication. DNA gives codes, or instruction for directing synthesis of specific structure and enzymes proteins within the cell. By monitoring these protein synthesis activities, the nucleus indirectly governs most cellular activities and serves as the cell's master. Three types of RNA are involved in protein synthesis. At first, DNA's genetic code for a particular protein is transcribed into a messenger-RNA, which leaves nucleus through the nuclear pores of the nuclear membrane. And, within the cytoplasm, m-RNA delivers the coded message to the ribosomal RNA, which "reads" message/code and translates it into the appropriate amino acids sequence for the designated protein being synthesized. Finally, transfer-RNA transfers the appropriate amino acids within the cytoplasm to their designated site in the protein under production. During cell replication, DNA ensures the continuing of the identical types of cell line within the body. Furthermore, in the gametes, the DNA blueprint serves to pass the genetic characteristics to future generation.

Generally, the nucleus may be:

- rounded➔e.g. in hepatocytes.
- indented (segmented)➔e.g. in neutrophils.
- binucleated➔e.g. in parietal cells, cardiac muscle cells.
- multinucleated➔e.g. in osteoclasts, skeletal muscle cells.
- very large (many DNA)➔e.g. in megakaryocytes.
- absent➔e.g. in mature erythrocytes, blood platelets.

The nucleus is surrounded by a **nuclear envelope** and contains chromatin and one or more nucleoli.

The Nuclear envelope

- ✓ surrounds nuclear material
- ✓ consists of outer and inner membrane
- ✓ perforated at intervals by nuclear pores
- ✓ Through this pores most ions and water soluble molecules to transfer b/n nucleus and cytoplasm

Chromatin: The term chromatin means "**colored material"** and refers to the fact that this material is easily stained for viewing with microscope, and it is composed mainly of coils DNA bound to basic protein called his tones. The DNA is so long that it has to be packed in an organization manner or it would get entangled like unraveled ball of string.

Nucleoli: The nuclei of most cells contain one or more lightly stained structures called nucleoli that actively engage in synthesizing of ribosomes. The nucleolus, unlike most of the organelles, does not have a limiting membrane. Instead, it is simply a structure that contains large amounts of RNA and protein of the type found in ribosomes. The nucleolus becomes considerably enlarged when a cell is actively synthesizing proteins. The genes of five separate chromosome pairs synthesize the ribosomal RNA and then store it in the nucleolus.

The Cytoplasm: The cytosol is the material of cell interior not occupied by the nucleus, containing a number of distinct, highly organized membrane-enclosed structures- the organelles- dispersed within a complex jelly like marrow called the cytosol. All cells contain six main types of organelles- the endoplasmic reticulum, Golgi complex, lysosomes, peroxisomes, mitochondria, and vacuoles. They are similar in all cells, but with some variations depending on the cell specialization. Each organelle is a separate compartment, containing different chemically setting for fulfilling a partial or cellular function. These organelles occupy about half of the total cell volume. The remaining part of the cytoplasm is cytosol.

Endoplasmic reticulum (ER)

The endoplasmic reticulum is a fluid-filled membrane system extensively present throughout the cytosol. The ER is one continuous organelle with many communicating channels. The two different types are smooth endoplasmic reticulum and the rough ER.. The smooth ER is a meshwork of interconnected tubules, whereas the rough ER projects outwards from the reticulum as stacks of flattened sacs. Though different in structure and function, they are continuous with each other.

The rough Endoplasmic Reticulum: The outer surface of the rough ER contains dark particles called ribosomes, which are ribosomal RNA protein complexes that produce protein under the direction of nuclear DNA. Messenger-RNA carries the genetic message from the nucleus to the ribosomes "workshop" where proteins are synthesized. Some ribosomes are "free" dispersed throughout the cytosol. The rough ER in association with ribosomes produces and releases a variety of proteins, into the fluid-filled space enclosed by the membrane. Some proteins for export as secretory products (hormones or enzymes). Other proteins are transported to sites within the cell for use in the construction of new plasma membrane or new organelle membrane. Cellular membrane contains predominantly fats and proteins. ER membrane also contains enzymes required for the synthesis of almost all the lipids needed for the production of new membranes. These lipids enter the ER lumen along with the proteins. This structure is well developed in cells producing digestive enzymes or in rapidly growing cells. Each ribosome is involved in producing only one type of protein. The free ribosomes synthesize enzyme proteins that are used intra-cellularly within the cytosol.

Smooth Endoplasmic Reticulum: Since it does not have ribosomes, it looks 'smooth' and does not produce proteins. It serves a variety of other functions that differ in cell types. In most cells, the smooth ER is sparse and serves in packaging and discharging site for protein molecules that are to be transported from the ER. All new proteins and fats pass from ER gathered in the smooth ER. Portions of the smooth ER then "bud off/pinch off", giving rise to 'transport vesicles', they contain the new molecule wrapped in a membrane derived from the smooth ER membrane. Transport vesicles move to the Golgi complex for further processing of their cargo. Some specialized cells have an extensive smooth ER, which has additional functions as follows:

- ✓ The smooth ER is well developed in cells specialized in lipid metabolism- cells that synthesize steroid hormones. The membrane wall of the smooth ER contains enzymes for synthesis of lipids. This is an additional site for synthesis in addition for ER to keep pace with demands for hormone secretion.

- ✓ In liver cells, the smooth ER contains enzymes involved in detoxifying harmful endogenous substances produced within the body by metabolism or exogenous substances entering the body from outside as drugs or other foreign compounds. The detoxifying enzymes alter toxic substances so that they could be easily eliminated in the urine. But unfortunately, in some instances the same enzyme transforms otherwise harmless substance into carcinogens that play a role in cancer development.
- ✓ The smooth ER has a special role in skeletal muscle cells. They have an elaborate network of smooth ER, which stores ionic calcium and plays a crucial role in the process of muscle contraction.

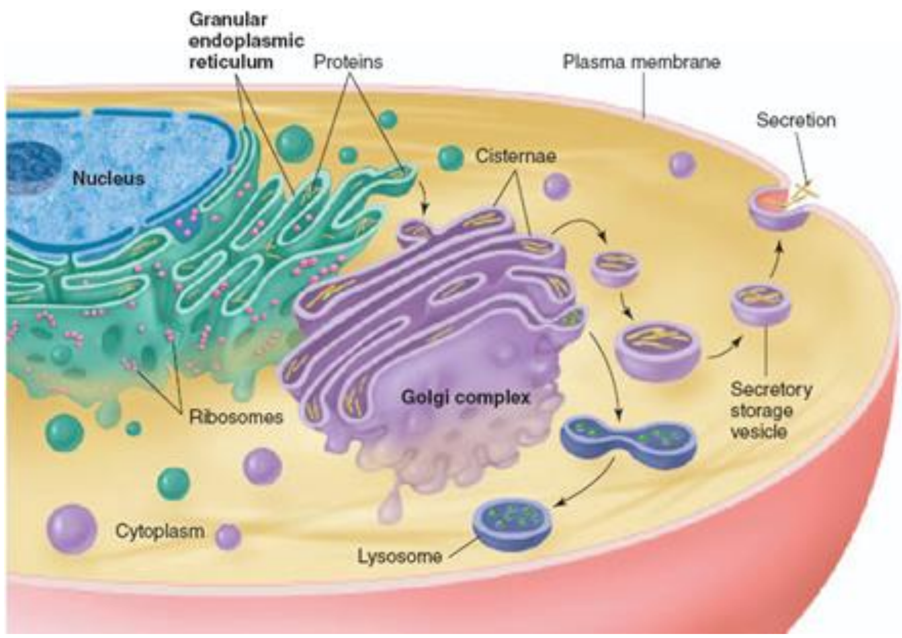


Fig:3.2. Golgi apparatus

The Golgi complex: The Golgi complex is elaborately associated with the ER and contains sets of flattened, curved, membrane- enclosed sacs, or cisternae, stacked in layers. Number of stacks vary in cells; cells specialized for protein secretion have hundreds of stacks, whereas some have only one. The majority of newly formed molecules budding off from the smooth ER enter a Golgi complex stacks. It performs the following important functions.

1. Processing the raw material into finished products. In the Golgi complex, the “raw” proteins from the ER are modified into their final state mainly by adjustment made in

the sugar attached to the protein. This is a very elaborate, precisely programmed activity, specific for each final product.

2. Sorting and directing finished product to their final destination. According to their function and destination, different types of products are segregated by the Golgi complex, i.e., molecules that are destined for secretion to the exterior, molecules that will eventually become part of the plasma membrane, and the molecules that will become incorporated into other organelles.
3. The smooth ER of the liver and kidney cells are responsible for the detoxification and inactivation of drugs. Enzymes within the smooth ER can inactivate or destroy a variety of chemicals including alcohol, pesticides, and carcinogens.
4. In skeletal muscle cells, a modified form of smooth ER stores Ca^{2+} to be released for muscle contraction.

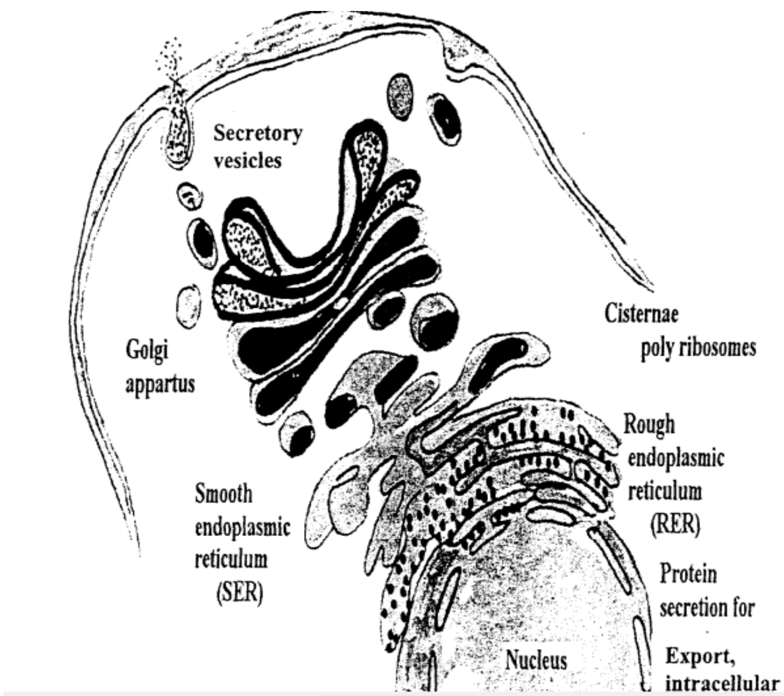


Fig: 3.3. Structure of endoplasmic reticulum and its relation with the Golgi apparatus and the nucleus.

Lysosomes: Lysosomes serve as the intracellular "digestive system". Lysosomes are membrane-enclosed sacs containing powerful hydrolytic enzymes capable of digesting and removing unwanted cellular debris and foreign materials such as bacteria that have been internalized within the cell. Lysosomes vary in size and shape, and about 300μm in a cell. Surrounding membrane confines these enzymes, preventing from destroying the cell that houses them. Extrinsic material to be attacked by lysosomal enzymes is brought into the interior of the cell through the process of endocytosis. If the fluid is internalized by endocytosis, the process is called pinocytosis. Endocytosis is also accomplished by phagocytosis.

In pinocytosis, ECF and a large molecule such as protein is engulfed. A specific molecule may bind to surface receptor, triggering pinocytosis- receptor-mediated endocytosis. Dynamin, a molecule forms rings wrapping around, severing the vesicle from the surface membrane in pinocytosis.

In phagocytosis, large multimolecular particles are internalized by endocytosis; this is achieved by only a few specialized cells- white blood cells that play an important role in the body's defense mechanism. When a leukocyte encounters large multimolecular particle, such as bacteria or tissue debris, it extends projection (pseudopodia) that completely surround or engulf the particle, forming an internalized vesicle that traps the large multimolecular particle within it.

A lysosome fuses with the membrane of the internalized vesicle and releases its contents of hydrolytic enzymes into the vesicle. These enzymes safely attack the microbes or other trapped material within the enclosed confines of the vesicle without damaging the remainder of the cell.

Lysosomes can take up old organelles such as mitochondria and break down into their component molecules. Those molecules that can be released are reabsorbed into the cytosol, and the rest are dumped out of the cell. The process by which worn-out organelles are digested is called **autophagy** a human liver cell recycles about half its content every week. In the inherited condition known as **lysosomal storage disease (Tay-Sachs disease)** lysosomes are not effective because they lack specific enzymes. As a result, harmful waste products accumulate disrupting the normal function of cells, often with fatal results

Peroxisome: Peroxisome is membrane-enclosed sacs containing oxidative enzymes and catalase that detoxify various wastes. Oxidative enzymes need oxygen to remove hydrogen from specific substance/molecule; such reactions are important in detoxifying various waste products within the cell or foreign compounds that have entered in, such as ethanol consumed in alcoholic drinks (in liver and kidneys). The major product generated is hydrogen peroxide; hydrogen peroxide itself is a powerful oxidant. It also contains catalase, and antioxidant enzyme decomposing hydrogen peroxide into harmless water and oxygen. This reaction is an important safety reaction that destroys deadly hydrogen peroxide, at the site of production, thereby preventing possible devastating escape into the cytosol. It is shorter and smoother than lysosome and several hundreds may present in one cell.

Peroximal disorders disrupt the normal processing of lipids and can severely disrupt the normal function of the nervous system by altering the structure of the nerve cell membrane

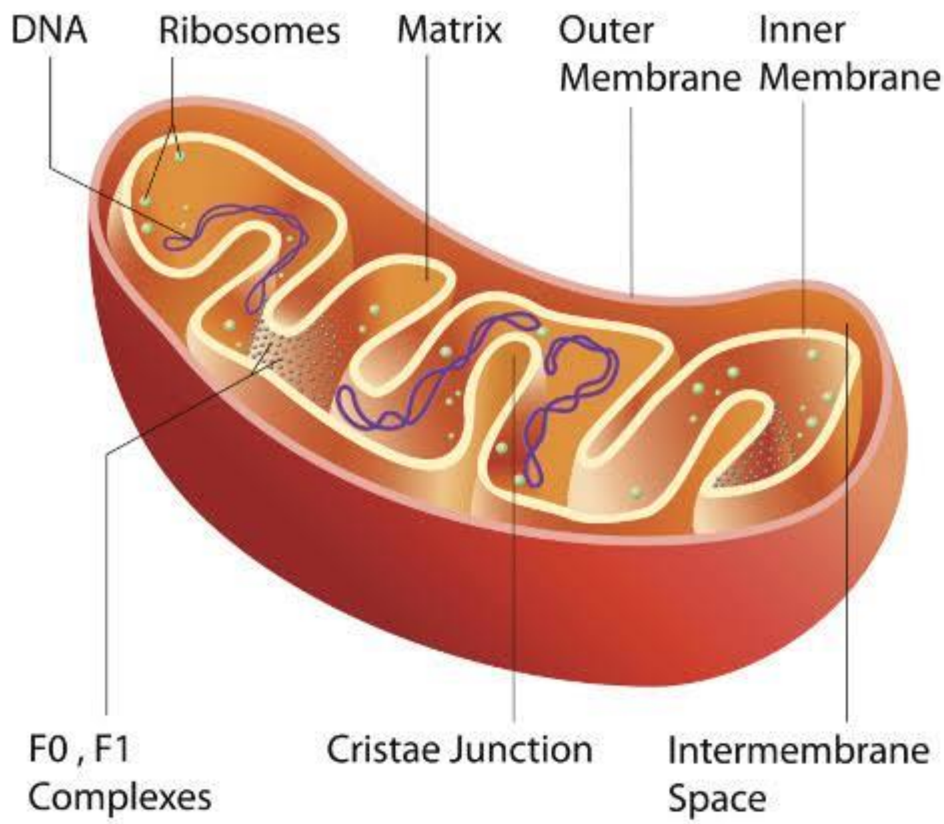
Mitochondria

Mitochondria are the ‘’power houses’’ of a cell; they extract energy from nutrients in food and transform it into usable form to energize cell activity. Their number varies depending on the energy needs of each particular cell types. A single cell may have few hundreds or thousands. Mitochondria are rod or oval shaped about the size of a bacterium. Each is enclosed by a double membrane - a smooth outer that surrounds the mitochondria, and an inner membrane that forms a series of enfolding or shelves called cristae, which project into an inner cavity filled with a jelly-like matrix (See figure 3.5). These cristae contain proteins that convert much of the energy in food into a usable form (the electron transport protein). The enfolding increase the surface area available for keeping these important proteins.

The matrix contains a mixture of hundreds of different dissolved enzymes (Citric acid cycle enzymes) that are important in preparing nutrient molecules for the final extraction of usable energy by the cristae proteins.

Carbon-hydrogen bonds in ingested food are the source of energy stored in the chemical forms. Body cell can extract energy from food nutrients and convert it into energy form that they can use. The high energy phosphate bonds of ATP contain adenosine with 3 phosphate groups. When high energy phosphate bond is split, a substantial amount of energy is released.

ATP is the universal energy carrier the common energy "currency" of the body. Cells can "cash in" ATP to pay the energy "price" for running the cellular machine. To get immediate usable energy cells can split terminal phosphate bond of ATP, which yields ADP with phosphate group attached - plus inorganic phosphate (Pi) plus energy. (See figure 3below).



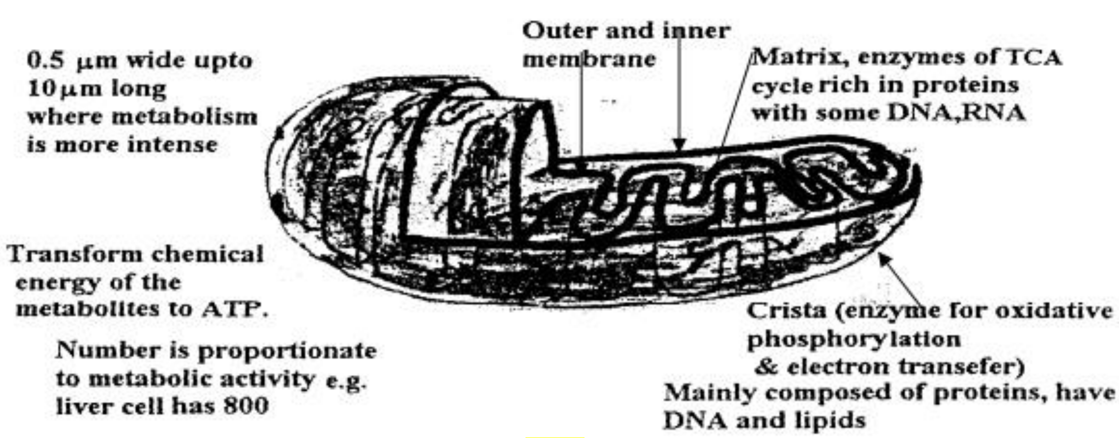


Fig. 3.5. Mitochondrial structure

Mitochondria are unusual organelles in two ways:

- In the matrix they have their own unique DNA called mitochondrial DNA.
- Mitochondria have the ability to replicate themselves even when the cell to which they belong is not undergoing cell division.

Chloroplasts

Chloroplasts are useful organelles among plastids as they highly participate in the process of photosynthesis which is a process by which plants synthesize their own food. They are located in outer surface of the cell to receive enough light. Chloroplasts are green colored due to the chlorophyll pigments found in its internal parts. Some of important characteristics of plant is its ability to carry out photosynthesis as the way they use in making their own food and pass through converting light energy in chemical energy.

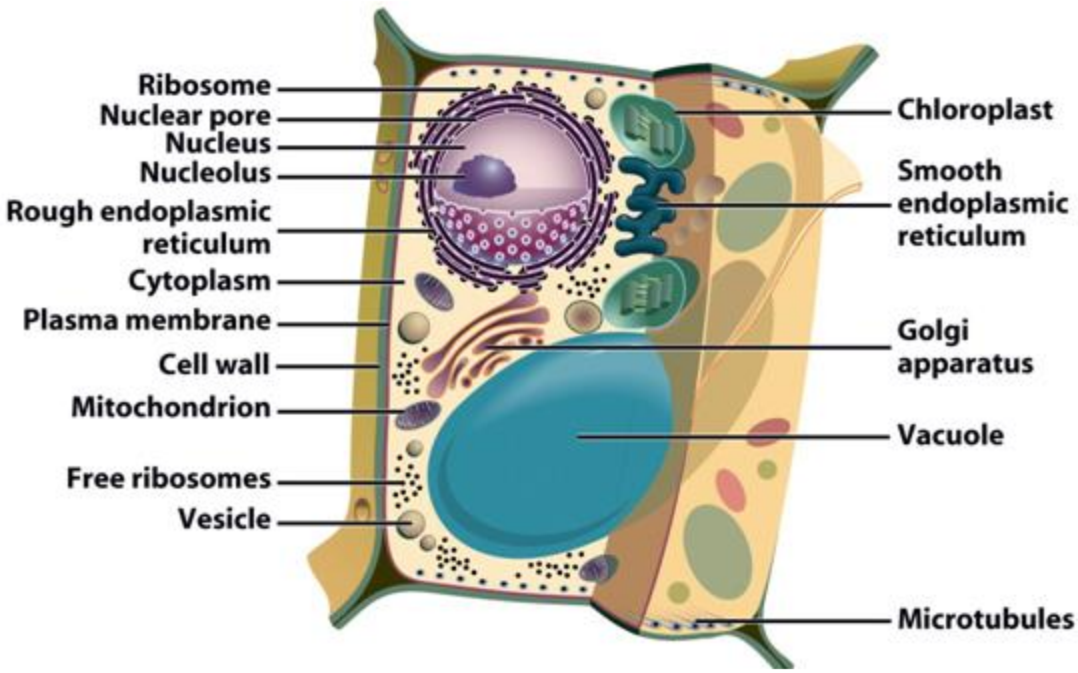


Fig: 3.6. Structure of plant cell

Vesicles are membrane bound sacs that are used to store or transport substances around the cell. *Lysosomes are actually Vesicles.*

Vacuoles are essentially larger Vesicles, and they are formed by the joining together of many Vesicles. They are membrane bound organelles that have no specific shape and contain water with a number of different compounds within it. Their function varies greatly depending on the type of cell they are part of. *In plant cells they are important in maintaining Turgor Pressure*.

Cytoskeleton

The cytoskeleton is a complex protein network that act as the “bone and muscle” of the cell. This necessary intracellular scaffoldings supports and organizes cellular components arrangements and to control their movements; this provides distinct shape, size to the cell.

This network has at least four distinct elements: Microtubules, Microfilaments, Intermediate filaments and Microtubular lattice

The different parts of the cytoskeleton are structures linked and functionally coordinated to provide integration of the cell. The microtubule is the largest of the group; slender, long, hollow tubes composed of a globular protein molecule (6 nm diameter) tubulin. They provide asymmetrical shape to the cell, such as a neuron with cell body and long axon. They coordinate numerous complex cell movements in transport of secretory vesicles from region to region of the cell, movements of cilia and flagella, distribution of chromosomes during cell division, microfilaments are important to cellular contractile system and as mechanical stiffeners. The microfilaments are the smallest of the cytoskeleton composed of protein molecule actin having a globular shape similar to tubulin. Generally, cytoskeletons determine/ provide the:

- ✓ shape of a cell
- ✓ structural support
- ✓ organizing its contents
- ✓ substances movement through cell (cilia, flagella and intracytoplasmic vesicles), and
- ✓ Contribute to movements of the cell as a whole.

Plasma/cell membrane

The plasma membrane is extremely thin layer of lipids and proteins forming outermost boundary of living cell and enclosing the intracellular fluid (ICF). It serves as a mechanical barrier that traps needed molecules within the cell; plasma membrane plays an active role in determining the composition of cell by selective permeability of substances to pass between the cell and its ECF environment. There are some differences in the composition of plasma membrane between cell types, which permit the cell to interact in different ways with essentially the same extracellular fluid (ECF) environment. The plasma membrane is a fluid lipid bilayer embedded with proteins. It appears as '***trilaminar'*** layer structure having two dark layers separated by a light middle layer as a result of specific arrangement of the constituent molecules.

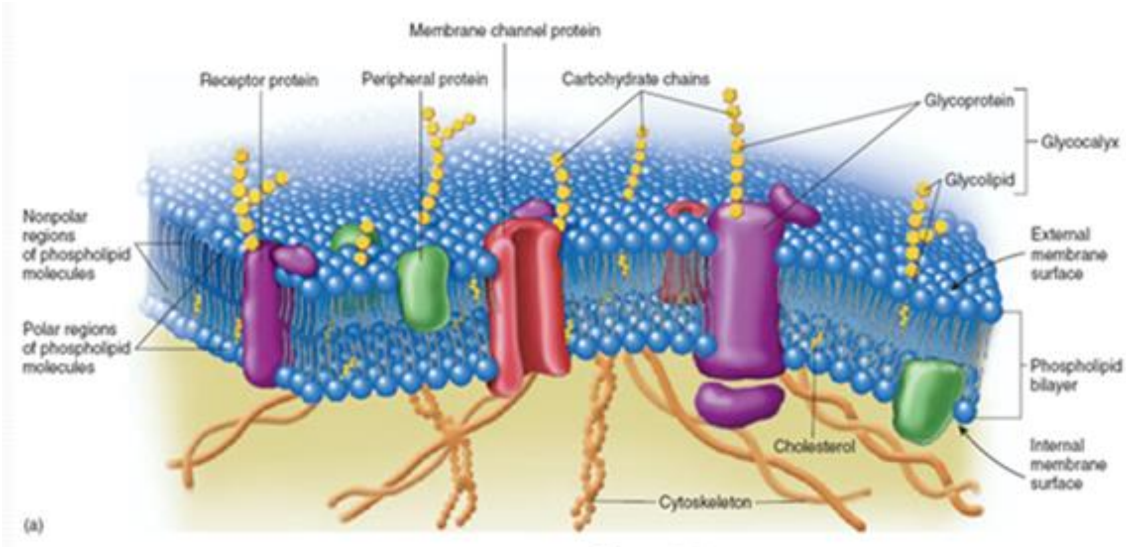


Fig: 3.7. Structure of the cell membrane

All plasma membrane are made up of lipids and proteins plus small amount of carbohydrates. Phospholipids are most abundant with a lesser amount of cholesterol. Phospholipids have a polar charged head having a negatively charged phosphate group and two non-polar (electrically neutral) fatty acid tails. The polar end is hydrophilic (water loving) because it can interact with water molecule, which is also polar; the non-polar end is hydrophobic (water fearing) and will not mix with water. Such two-sided molecule self-assemble into a lipid bilayer, a double layer of lipid molecules when in contact with water. The hydrophobic tails bury themselves in the center away from the water, while the hydrophilic heads line up on both sides in contact with water. The water surface of the layer is exposed to ECF, whereas the inner layer is in contact with the intracellular fluid (ICF). The lipid is fluid in nature, with consistency like liquid cooking oil. Cholesterol provides to the fluidity as well as the stability; cholesterol lies in between the phosphate molecules, preventing the fatty acid chain from packing together and crystallizing that could decrease fluidity of the membrane. Cholesterol also exerts a regulatory role on some of the membrane proteins. For fluidity of the membrane, it gives flexibility to the cell to change its shape; transport processes are also dependent on the fluidity of the lipid bilayer. The membrane proteins are either attached to or inserted within the lipid bilayer; some extending through the entire membrane thickness; they have polar region at both ends joined by a non-polar central portion. Other proteins are on either the outside or inner surface, anchored by interactions with proteins that spans the membrane or by attachment to the lipid bilayer. On account of membrane fluidity, many proteins float freely, although the mobility of protein that have special function in a particular area of the membrane is restricted - this gives ever changing mosaic pattern of the protein embedded in the lipid layer. Only the outer surface of the plasma membrane contains a small amount of carbohydrate. Short-chain carbohydrates are bound primarily to membrane proteins and to a lesser extent to lipids, forming glycoproteins and glycolipids.

The plasma membrane is actually asymmetrical; the two surfaces are not the same; carbohydrate is only on the outer surface; different amount of different proteins are on the outer and inner surfaces and even the lipid structures of the outer and inner half is not the same. The plasma membrane is highly complex, dynamic, regional differentiated structure. The lipid layer forms the primary barrier to diffusion, whereas proteins perform most of the specific membrane functions.

Lipid bilayer forms the basic structure of the membrane, is a barrier to passage of water-soluble substances between the ICF and ECF; and is responsible for the fluidity of the membrane.

Membrane proteins are variety of different proteins within the plasma membrane; have the following special functions: 1. some form water-filled passage ways or channels, across the lipid bilayer; such channels allow ions to pass through without coming in direct contact with lipid interior. The channels are highly selective; they can selectively attract or repel particular ions. This selectively attracts or repels particular ions. This selectivity is to specific charged amino acids group. Number and kind of channels vary in cells. Channels open and close in response to a controlling mechanism. 2. Other proteins serve as carrier molecule that transport specific molecule that cannot cross on their own. They differ in cells, e.g., thyroid epithelial cell possesses carriers for iodine. 3. Many proteins on the outer surface serve as ‘receptor sites’ that recognize and bind with specific molecules in the cell environment. This binding triggers a series of membrane and intracellular events that alter the activity of the target cell. In this way hormones influence specific cell, even though every cell is exposed to the same chemical messenger via its widespread distribution by the blood 4. Another group of proteins act as membrane-bound enzymes that control specific chemical reactions on either side of the plasma membrane e.g., outer layer of the plasma membrane of skeletal muscle contains enzyme ACh-esterase that destroys the chemical messenger that triggers contraction. 5. Some proteins are arranged as filaments network/meshwork on the inner side and are secured to certain internal protein elements of the cytoskeleton. They maintain cell shape. 6. Other proteins function as cell adhesion molecules (CAMs). These molecules protrude from the membrane surface that grip each other and grip the connective tissue fibers that interlace between cells. 7. Some proteins, especially in conjunction with carbohydrate are important in the cell's ability to recognize 'self' and in cell-to-cell interactions.

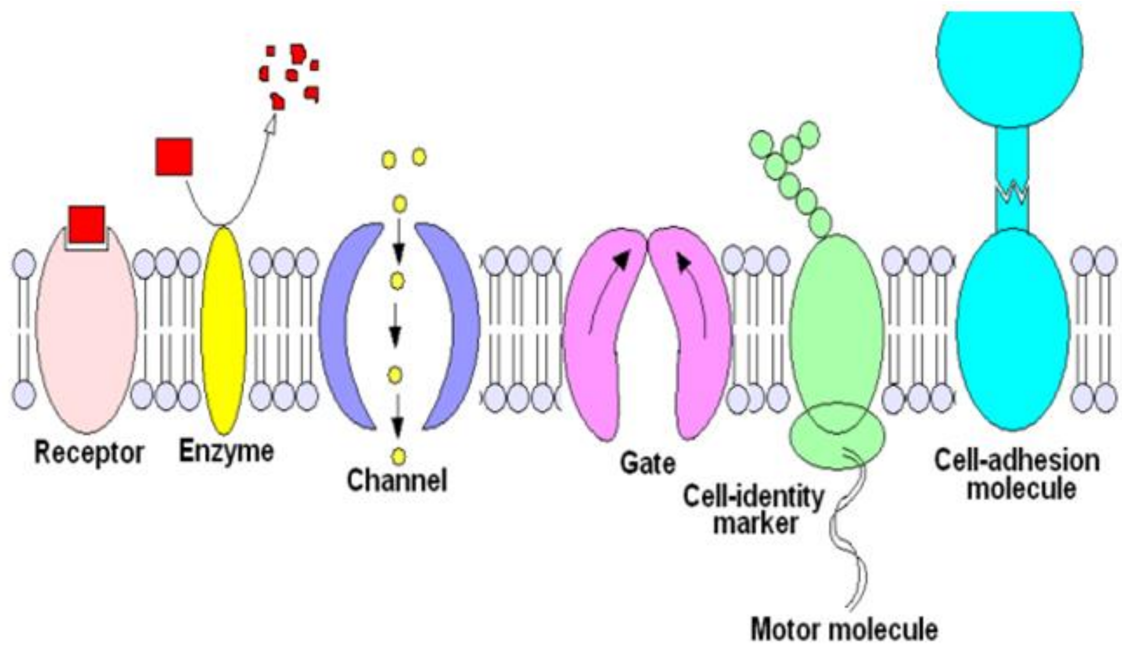


Fig: 3.8. Membrane proteins

Membrane Carbohydrate: Short-chain carbohydrate on the outer membrane surface serves as self-identity marker enabling cells to identify and interact with each other in the following ways:

- Recognition of “self” and cell-to-cell interactions. Cells recognize each other and form tissues; complex carbohydrates act as a “trademark” of a particular cell type, for recognition.
- Carbohydrate-containing surface markers are important in growth. Cells do not overgrow their own territory. Abnormal surface markers present in tumor cells, and abnormality may underline uncontrolled growth.
- Some CAMS have carbohydrate, on the outermost tip where they participate in cell adhesion activity.

Functions of biological membranes

The phospholipid bilayers provide the basic structure of the membrane and they also restrict entry and exit of polar molecules and ion. The other molecules in the membrane have a variety of function:

- **Channel protein and carrier protein:** these proteins are involved in the selective transport of polar molecule and ion across the membrane
- **Enzymes:** membrane proteins sometimes act as enzymes, For example, the microvilli on epithelial cells lining some part of the gut contain digestive enzymes in their cell surface membrane
- **Receptor molecules:** proteins have very specific shapes and this makes them ideal as receptor molecules for chemical signaling between cells.
    - For example, hormones are chemical messengers, which circulate in the blood but, only bind to specific target cells, which have the correct receptors sites. Neurotransmitters, the chemicals that enable nerve impules from one nerve cell to the next, also fit into specific receptor proteins in nerve cells.
- **Antigens**: these act as cell identity markers or "name tag". They are glycoproteins that is proteins with branching carbohydrates side chains like antennae. There is an enormous number of possible shapes to these side chains, so each type of cell can have its own specific markers.

  This enables cells to recognize other cells, and to behave in an organized way, for example, during development of tissues and organs in multicellular organisms. It also means that foreign antigens can be recognized and attacked by the immune system.

- **Glycolipids-** also have branching carbohydrate side chain and are involved in cell-cell recognition. They may act as a receptor sites for chemical signals. With glycoproteins they also involved in sticking the correct cell together in tissues. Eg. sperm recognition of ova
- **Energy Transfer** in photosynthesis and respiration proteins take part in the energy transfer systems that exist in the membranes of chloroplast and mitochondria respectively.
- **Cholesterol**: acts like a plug, reducing even further the escape or entry of polar molecules through the membrane.

3.1.3 Cellular diversity

Self-test
1. What dictates the diversity of cells?
2. Why cells are diverse in their shape, size and structure?

Cells are found in different organisms, and are very diverse in their size, shape and their internal structure and this also applies to cells found in the same organism. This diversity is influenced by their roles and function within organism's body.

3.1.3.1 Cell Shape

Cells have different shapes due to appropriate function. It is possible to find other cells which are flat, most of these cells are body cells and their function is protecting and covering body surface. Nerve cells have long extensions. Skin cells have a shape which is flat. Egg cells have shape which is like sphere, and some bacteria are rod in shape. Some plant cells are rectangular.

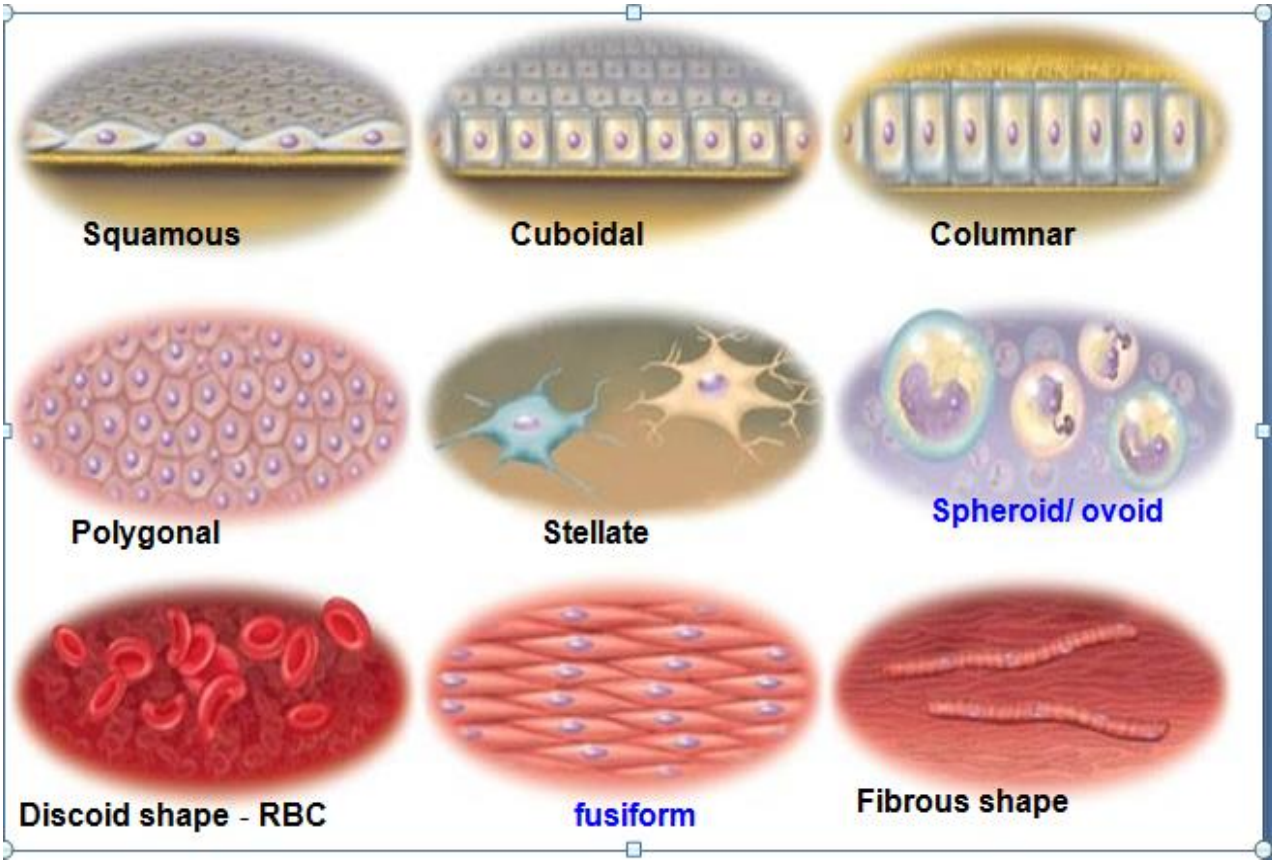


Fig: 3.9. Various types of animal cells (shape)

3.1.3.2 Cell Size

Some cell can be seen without using magnification instruments as they are enough to be seen by the naked eye.

Example, egg of birds/reptiles and a neuron cell of giraffe, which is 2 meters in length.

3.1.4 Transport across the cell membranes

Self-Test

1. What dictates the diversity of cells?
2. How osmotic condition of the body is kept constant?
3. List dawn the major transport mechanisms that occur in organisms?

The plasma membrane is selectively permeable. Lipid-soluble substances and small ions can passively diffuse through the plasma membrane down their electro-chemical gradients. Highly lipid-soluble particles are able to dissolve in the lipid bilayer and pass through the membrane. Uncharged/non-polar molecules oxygen, carbon dioxide and fatty acids are highly lipid-soluble and readily permeate the membrane. Charged particle sodium/potassium ions and polar molecules such as glucose and proteins have low lipid solubility, but are very soluble in water. For water-soluble ions of less than 0.8 nm diameters, protein channels serve as an alternate route for passage. Ions for which specific channels are available can permeate the plasma membrane. Particles with low lipid-permeability and too large for channels, cannot permeate the membrane on their own. The phospholipid bilayer is a good barrier around cells, especially to water soluble molecules. However, for the cell to survive some materials need to be able to enter and leave the cell. There are 4 basic mechanisms:

1. Diffusion and facilitated diffusion
2. osmosis
3. active transport
4. bulk transport

Two forces are involved in facilitating movement across the plasma membrane**:**

1. Forces that do not require the cell to expend energy for movement – passive force
2. Forces requiring energy (as ATP) to be expended to transport across the membrane - active force

Diffusion

Diffusion is the net movement of molecules (or ions) from a region of their high concentration to a region of their lower concentration. The molecules move down a concentration gradient. Molecules have kinetic energy, which makes them move about randomly. All molecules in liquid and gases are in continuous random motion in any direction as they have more room to move before colliding with another. As a result of this haphazard movement, the molecules frequently collide bouncing off each other in different directions.

The greater the concentration, the greater the likelihood of collision. Such a difference in concentration in molecules between two adjacent areas is chemical /concentration gradient. The net movement of the molecule by diffusion will be from the higher area of concentration to the area of lower concentration.

Certain additional factors that influence the rate of net diffusion across a membrane are:

1. permeability of the membrane
2. surface area of the membrane

3. molecular weight of the substance (lighter one diffuses rapidly)
4. distance through which diffusion must take place

N.B:- Increasing all the factors increases rate of net diffusion, except distance - thickness, that if increased, decreases the rate of diffusion; and molecular weight if increased, decreases rate of diffusion.

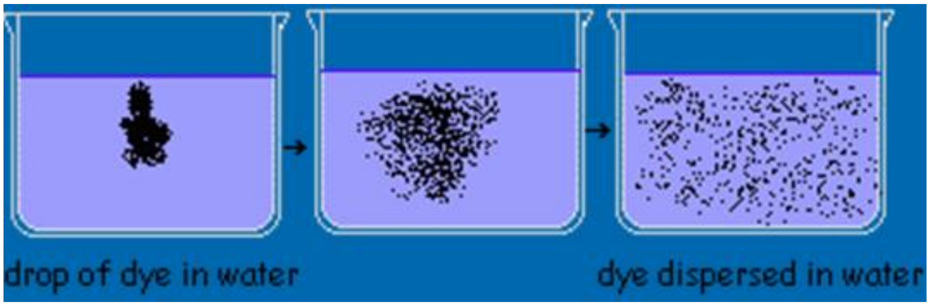


Fig: 3.10. Diffusion of molecules

As a result of diffusion molecules reach an equilibrium where they are evenly spread out. This is when there is no net movement of molecules from either side.

Movement along electrical gradient

Movement of charged particles is also affected by their electrical gradient. If a relative difference in charges exists between two adjacent areas, the cations tend to move towards more negatively charged area, whereas the anions tend to move toward the more positively charged areas. The simultaneous existence of an electrical and concentration (chemical) gradient for a particular ion is referred to as an electro-chemical gradient.

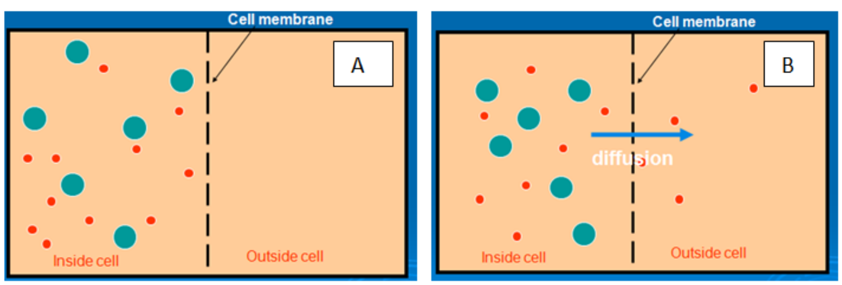


Fig: 3.11. Concentration gradient (A) and difussion (B)

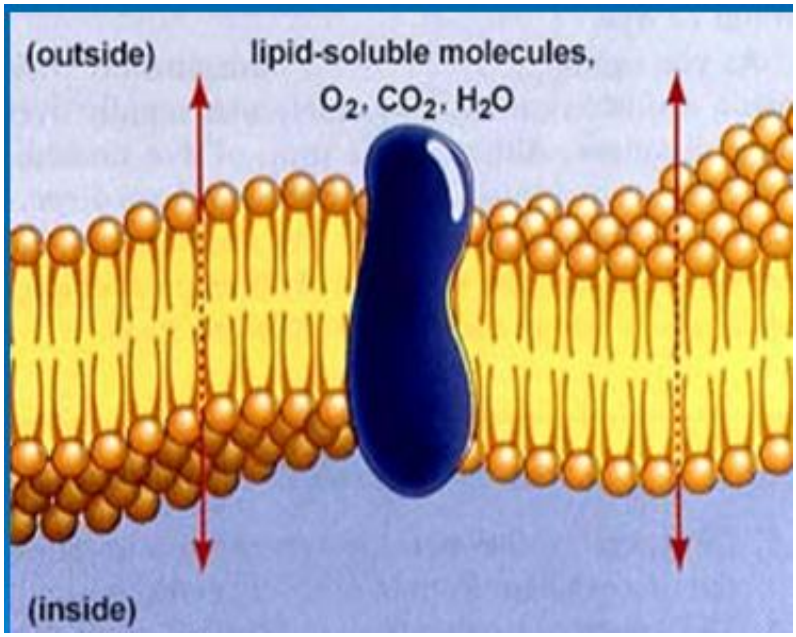


Fig:3.12. Diffusion of lipid molecules

Carrier- Mediated Transport

All carrier proteins span the thickness of the plasma membrane and are able to undergo reversible changes in shape so that specific binding site can alternately be exposed at either side of the membrane. As the molecule to be transported attaches to a binding site on the carrier on one side of the membrane, it triggers a change in the carrier shape that causes the same site to be exposed to the other side of the membrane. Their having movement in this way, the bound molecule detaches from the carrier. This transport displays three characteristics:

1. **Specificity:** each cell possesses protein specified to transport a specific substance or few closely-related chemical compounds amino acid cannot bind to glucose carrier, but similar amino acids may use the same carrier. Type of carriers vary in cells. A number of inherited disorders involve defects in transport system for a particular substance.
2. **Saturation**: in a given time only a limited amount of a substance can be transported via a carrier; limited number of carrier site are available within a particular plasma membrane for a specific molecule. This limit is known as transport maximum (Tm). The substance's rates of transport across the membrane are directly related to its concentration. When the Tm is reached, the carrier is saturated, and the rate of

transport is maximum. Further increase in the substance concentration is not accompanied by corresponding increase in the rate of transport. Saturation of carrier is a critical rate-limiting factor to the transport of selected substances across the plasma membrane in kidney and the intestine. There is a mechanism to increase the number of carriers in the plasma membrane.

3. **Competition:** Several closely related compounds may compete for ride across the plasma membrane on the same carrier.

Facilitated Diffusion

Facilitated diffusion uses a carrier protein to facilitate the transfer of a particular substance across the membrane "downhill" from higher to lower concentration. This process is passive and does not require energy because movement occurs naturally down a concentration gradient. Active transport, on the other hand, requires the carrier to expend energy to transfer its passenger "uphill" against a concentration gradient from an area of lower concentration to an area of higher concentration. Active transport requires protein carrier to transfer a specific substance across the membrane, transporting against concentration gradient. Carrier phophorylation increases the affinity for its passenger. The carrier has ATPase activity splitting high-energy phosphate from an ATP to yield ADP plus a free Pi. This phosphate group gets bound to the carrier.

Phosphorylation and binding of particle on the low concentration side induces a conformational change in the carrier protein so that passenger is now exposed to the high concentration side of the membrane. This change in carrier shape is accompanied by dephosphorylation. Removal of phosphate reduces the affinity of the binding site for the passenger, so the passenger is released on the high concentration side. The carrier then returns to the original conformation. This active transport mechanisms are often called ‘pumps’, analogous to lift water by pump that need energy to lift water against the downward pull of gravity; Hydrogen-pump, Na-KATPase pump (Na-K-Pump).

Osmosis

Osmosis is the net diffusion of water down its own concentration gradient. Water can readily permeate the plasma membrane. The driving force for diffusion of water is its concentration gradient from area of higher water concentration (low solute) to the area of lower water (high solute) concentration. This net diffusion of water is known as osmosis. Special mechanisms are used to transport selected molecules unable to cross the plasma membrane on their own.

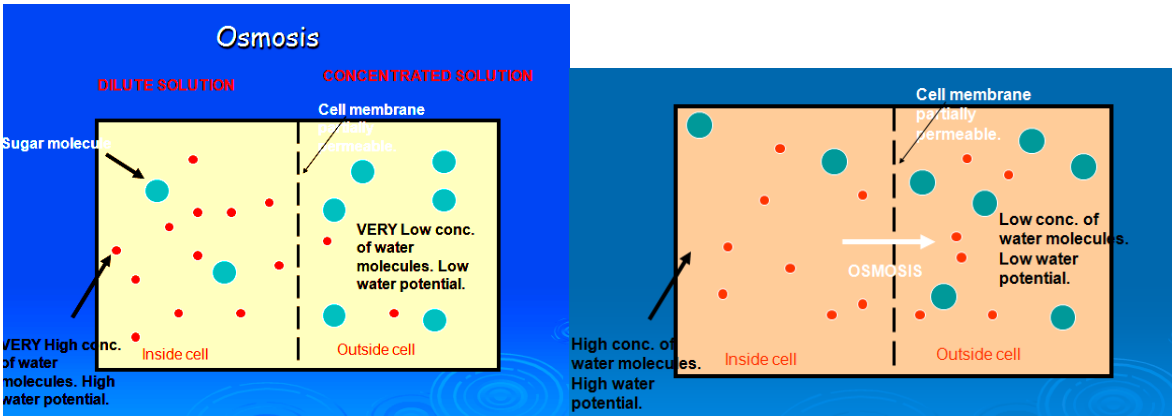


Fig: 3.13. Movement across membranes

Active transport

Active transport is energy consuming transport of molecules or ions across a membrane against its natural tendency to diffuse in the opposite direction. The movement of molecules in active transport is in one direction only; unlike diffusion that is reversible the energy is supplied by the broke down of ATP, which energy carrier is made in respiration

The major ions within the cells and their surrounding are sodium (Na^+), potassium (K^+) and chloride (Cl^-). In recent years it has been shown that the cell surface membrane of most cell have sodium pump is coupled with a potassium pump that actively moves potassium ion from outside to inside the cell. The combined pump is called the sodium pump (Na^+-K^- pump).

The pump is a carrier protein that spans across the membrane from one side to the other. The transfer of sodium and potassium across the membrane is brought about by the changes in the shape of the protein. Note that for every 2K+ions taken into the cell, 3Na+ ions are removed.

Thus a potential difference is built up across the membrane, with the inner side of the cell being negative. This tends to restrict the entry of negatively charged ions (anions) such as chloride and favoring diffusion of cations into the cell. This explains why *chloride concentration inside red cell is less than the outside despite the fact that chloride ions can diffuse in and out by facilitated diffusion*

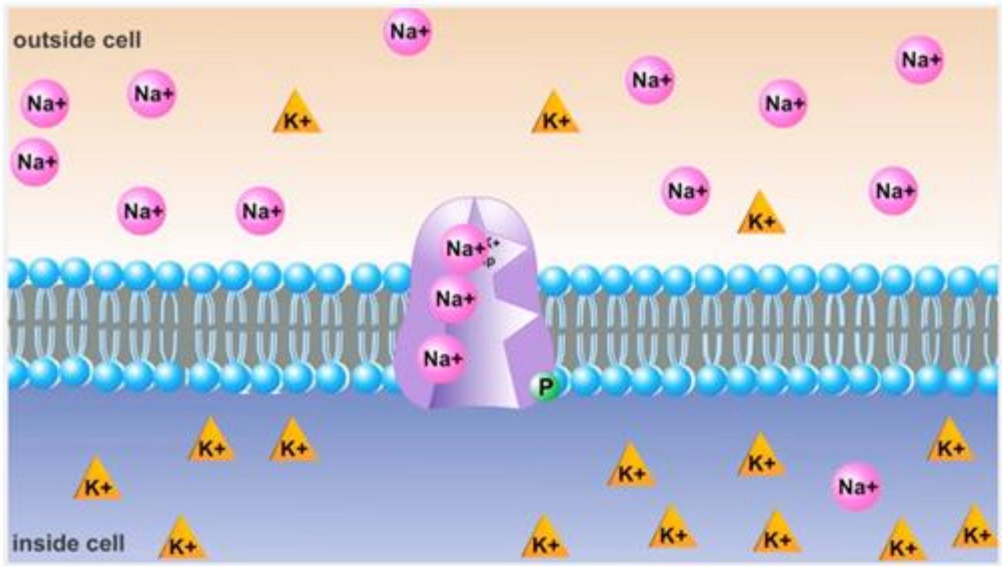


Fig: 3.14. Sodium-potasium pump

Similarly, positively charged ions (cations) tend to be attracted in to cell. Thus both concentration and charge are important in deciding the direction in which ions cross the membrane. The pump is essential in controlling the osmotic balance in animal cells (osmoregulation) . If the pump is inhibited, the cell swells and brusts because of the building-up of Na+, which results in excess water entering in to the cell by osmosis . The pump is also important in maintaining electrical activity in nerve and muscle cells and in driving active transport of some other substances such as sugar and amino acids. In addition, high concentrations of potassium are needed inside cells for protein synthesis, glycolysis, photosynthesis and other vital processes.

Na+-K+-pump plays three important roles

1. It establishes sodium and potassium concentration gradients across the plasma membrane of all cells; these gradients are important in the nerve and muscle to generate electrical signals.

2. It helps regulate cell volume by controlling the concentration of solutes inside the cell and thus minimizing osmotic effects that would induce swelling or shrinking of the cell.

3. The energy used to run the pump also indirectly serves as the energy source for the co-transport of glucose and amino acids across the membrane (intestine and kidney cell).

Table 3.1 How molecules cross cell membrane

	Active/ Passive	Molecules that Move	Direction	Energy Needed?	Protein Needed?
Diffusion	Passive	small, hydrophobic	down gradient (toward low conc.)	no	no
Osmosis	Passive	water	toward high conc. of solutes	no	no
Facilitated Diffusion	Passive	any (specific transporter)	down gradient (toward low cons.)	no	yes
Active Transport	Active	any (specific transporter)	specific: in or out, dep. on transporter	yes	yes

Exocytocis and Endocytisis

Vesicular Transport The special cell membrane transport system selectively transports ions and small polar molecules. But large polar molecules and even multimolecular material may leave or enter the cell, such as hormone secretion or ingestion of invading microbe by leukocytes. These materials cannot cross the plasma membrane but are to be transferred between the ICF and ECF not by usual crossing but by wrapped in membrane. This process of transport into or out of the cell in a membrane-enclosed vesicle is - vesicular transport. Transport into the cell is termed endocytosis, whereas transport out of the cell is called exocytosis. In endocytosis, the transported material is wrapped in a piece of the plasma membrane, thus gaining entrance to the interior of the cell. Endocytosis of fluid is called pinocytosis cell (drinking), whereas endocytosis of large multimolecular particle is known as phagocytosis (cell eating).

Endocytosis and exocytosis are active processes involving the bulk transport of materials through membranes, either in to cells (endocytosis)or out of cells (exocytosis).

Endocytosis occurs by an in folding or extension of cell surface membrane to form a vesicle or vacuole. It is of two types.

Phagocytosis (cell eating) material taken up is in solid form. Cells specializing in the processes are called phagocytes and are said to be phagocytic. The sac formed during the uptake is called a phagocytic vacuole.

Pinocytosis (cell drink) material taken up is in liquid form. Vesicles formed are extremely small, in which case the process is known as micropinocytosis and the vesicles as micropinocytic vesicles. Pinocytosis is used by the human egg cell to take up nutrients from the surrounding follicle cells.

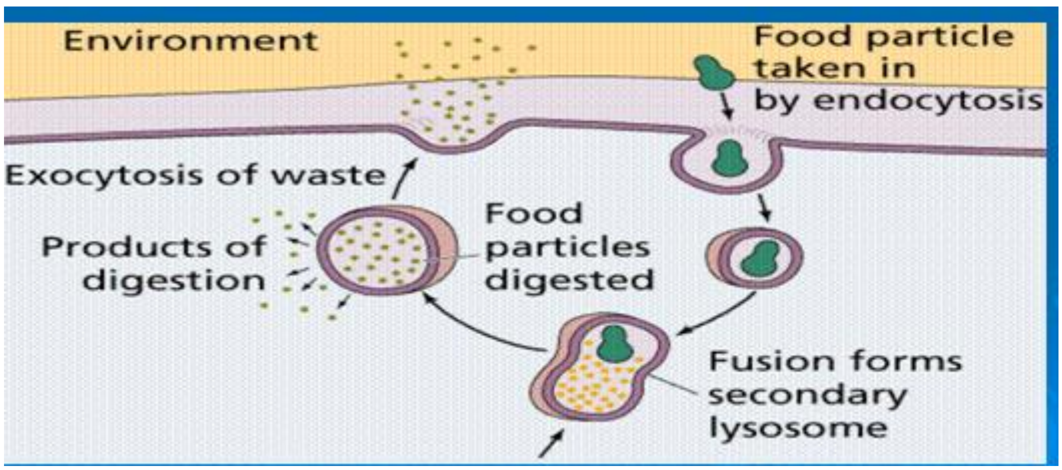


Fig: 3.15. Exocytosis

Exocytosis is the reverse process of endocytosis. Waste materials such as solid and undigested remains from phagocytic vacuoles may be removed from cells or useful materials may be secreted. Secretion of enzymes from the pancreas is achieved in this way. Plant cells use exocytosis to export the materials needed to form cell wall.

Activity

1. What is autophagy?
2. Describe the change in domination of types of plastids when a banana fruit gets ripened.
3. Describe the different sizes and shapes of cells? Why are so varied?

4. Compare and contrast respiration and biosynthesis.
5. write down roles of different components of cell membrane
6. How osmotic condition of the body is kept constant?
7. Which of the means of transport of materials in cells are active and which are passive? What is the difference?
8. Differentiate endocytosis from exocytosis?
9. Explain the development of cell theory
10. What are the factors affecting the rate of diffusion?

Unit 4
Cellular Metabolism and Metabolic Disorders

Learning Objectives:

This chapter deals with the chemical reactions which keep us alive-metabolism. Therefore, at the end of this chapter students are expected to

- ✓ define and understand the different types of metabolism and ~~,~~metabolic pathways
- ✓ understand the energy transduction in a cell
- ✓ describe the nature and role of enzymes in metabolism
- ✓ describe the main processes in photosynthesis and understand major photosynthetic apparatus
- ✓ understand the central metabolic pathways(glycolysis, kreb's cycle and electron transport chain)
- ✓ know some of the metabolic disorders of public health concern

4.1 Cellular metabolism

Self-Test

1. *Where do cells obtain energy and why do they need it?*
2. *How cells gain energy?*
3. *What is metabolism and metabolic pathway**?***

Living cells are in a constant activity. Macromolecules are assembled and broken down, substances are transported across cell membranes, and genetic instructions are transmitted. All of these cellular activities require energy.

Living organisms are unique in that they can extract energy from their environments and use it to carry out activities such as movement, growth and development, and reproduction. But the basic question is how living organisms or, their cells extract energy from their environments, and how cells use this energy to synthesize and assemble the components from which the cells are made. The answers to these questions lie in the enzyme-mediated chemical reactions that take place in living matter (metabolism). Hundreds of coordinated, multistep reactions, fueled by energy obtained from nutrients and/or solar energy, ultimately convert readily available materials into the molecules required for growth and maintenance.

Metabolism is thus the sum of chemical reactions that takes place within each cell of a living organism and that provides energy for vital processes and synthesizing of new organic materials. Broadly, these reactions can be divided into **catabolic reactions** that convert nutrients to energy and **anabolic reactions** that lead to the synthesis of larger biomolecules.

In metabolism, a series of chemical reactions in which the product of one reaction is the substrate for the next reaction is called a **metabolic pathway.** Catabolic pathways release energy by breaking down larger molecules into smaller molecules. Anabolic pathways use the energy released by catabolic pathways to build larger molecules from smaller molecules, insuring the continual flow of energy within an organism. The reactants and products of these chemical reactions are **metabolites**. The major classes of metabolites include proteins, carbohydrates, nucleotides, lipids, coenzymes, and cofactors. These classes of compounds encompass an enormous diversity of molecular structures, physicochemical properties, functions, and abundances. Due to the analytical challenges posed by this diversity, most studies require division into subsets of metabolites. The most common criteria for this distinction rely on the hydrophilic (polar) and hydrophobic (nonpolar) nature of metabolites. Polar metabolites are soluble in aqueous solutions and include most sugars, purines and pyrimidines, nucleotides and nucleosides, acyl carnitines, organic acids, hydrophilic acids, amino acids, and phosphorylated compounds. These metabolites include most of the reactants and products involved in cellular respiration (e.g., glycolysis, the Kreb's cycle, or in other pathways) and in the production of building blocks for synthesis of large biopolymers such as DNA, RNA, proteins, and oligosaccharides. The nonpolar or hydrophobic metabolites are commonly lipids. These metabolites function in energy storage, membrane structure, and signal transduction.

At the cellular level of organization, the main chemical processes of all living matter are similar, if not identical. This is true for animals, plants, fungi, or bacteria; where variations occur (such as, the secretion of antibodies by some molds), the variant processes are but variations on common themes. Thus, all living matter is made up of large molecules called proteins, which provide support and coordinated movement, as well as storage and transport of small molecules, and, as catalysts, enable chemical reactions to take place rapidly and specifically under mild temperature, relatively low concentration, and neutral conditions (i.e., neither acidic nor basic).

The chemical reactions that take place in living cells are similar as well. Green plants use the energy of sunlight to convert water (H2O) and carbon dioxide (CO2) to carbohydrates (sugars and starches), other organic (carbon-containing) compounds, and molecular oxygen (O2). The process of photosynthesis requires energy, in the form of sunlight, to split one water molecule into one-half of an oxygen molecule (O2; the oxidizing agent) and two hydrogen atoms (H; the reducing agent), each of which dissociates to one hydrogen ion (H+) and one electron. Through a series of oxidation-reduction reactions, electrons (denoted e−) are transferred from a donating molecule (oxidation), in this case water, to an accepting molecule (reduction) by a series of chemical reactions; this "reducing power" may be coupled ultimately to the reduction of carbon dioxide to the level of carbohydrate. In effect, carbon dioxide accepts and bonds with hydrogen, forming carbohydrates ($C_n[H_2O]_n$). Living organisms that require oxygen reverse this process: they consume carbohydrates and other organic materials, using oxygen synthesized by plants to form water, carbon dioxide, and energy. The process that removes hydrogen atoms (containing electrons) from the carbohydrates and passes them to the oxygen is an energy-yielding series of reactions. In plants, all but two of the steps in the process that converts carbon dioxide to carbohydrates are the same as those steps that synthesize sugars from simpler starting materials in animals, fungi, and bacteria. Similarly, the series of reactions that take a given starting material and synthesize certain molecules will be used in other synthetic pathways are similar, or identical, among all cell types. For instance, from a metabolic point of view, the cellular processes that take place in a lion are only marginally different from those that take place in a dandelion.

4.1.1 Enzymes and their role in metabolism

Self-test

Most chemical reactions within cells do not occur spontaneously. Instead, they need a catalyst to get them started. Why do you think this is so?

In many cases, heat may be a catalyst, but this is inefficient because heat cannot be applied to molecules in a controlled fashion. Thus, most chemical reactions require biological catalyst called enzymes.

What are enzymes and why they are needed?

Enzymes are protein catalysts that speed biochemical reactions by facilitating the molecular rearrangements that support cell function. Enzymes speed up (**catalyze**) chemical reactions; in some cases, enzymes can make a chemical reaction millions of times faster than it would have been without it. Almost all metabolic processes in the cell need enzyme catalysis in order to occur at rates fast enough to sustain life.

Enzymes bind with particular reactants until the chemical reaction occurs, then free themselves. Thus, at any given time, the numerous pathways involved in building up and breaking down cellular components must be monitored and balanced in a coordinated fashion. To achieve this goal, cells organize reactions into various enzyme-powered pathways.

How do enzymes speed up chemical reactions?

Enzymes speed up reactions by lowering activation energy. Many enzymes change shape when substrates bind. This is termed "induced fit", meaning that the precise orientation of the enzyme required for catalytic activity can be induced by the binding of the substrate.

What is activation energy?

4.1.2 Chemical nature and classification of enzymes

All known enzymes are proteins with the exception of recently discovered RNA enzymes. Some enzymes may additionally contain a non-protein group. Enzymes are high molecular weight compounds made up principally of chains of amino acids linked together by peptide bonds.

Many enzymes require the presence of other compounds (cofactors) before their catalytic activity can be exerted. This entire active complex is referred to as the **holoenzyme**; i.e., apoenzyme (protein portion) plus the cofactor (coenzyme, prosthetic group or metal-ion-activator). Thus, on the basis of differences in chemical nature, the enzymes may be described as follows:

- **Simple enzymes:** Simple enzymes are made up of only protein (polypeptide). They contain no chemical groups other than amino acid residues. Digestive enzymes such as pepsin and trypsin are of this nature.

- **Conjugate Enzymes**: It is an enzyme which is formed of two parts – a protein part called apoenzyme (e.g., flavoprotein) and a non-protein part named cofactor. The complete conjugate enzyme, consisting of an apoenzyme and a cofactor, is called holoenzyme. There can be an enzymatic activity only when both components (apoenzyme and cofactor) are present together. The cofactor is sometimes a simple divalent metallic ion (e.g. Ca, Mg, Zn, Co, etc), and sometimes a nonprotein organic compound. However, some enzymes require both kinds of cofactors. If the cofactor is firmly bound to the apoenzyme, it is called **prosthetic group**. For example, cytochromes are the enzymes that possess porphyrins as their prosthetic groups. If, instead of being more or less permanently bound to the apoenzyme the cofactor attaches itself to the apoenzyme only at the time of reaction, it is called a **coenzyme**.

- **Metallo-enzymes:** The metal cofactors involved in enzymic reactions are monovalent (K^+) and divalent cations (Mg^{++}, Mn^{++} and Cu^{++}). These may be loosely held by the enzyme, or as in some cases, go into the composition of the molecule itself. If the metal forms part of the molecule, as iron of haemoglobin or cytochrome is, the enzymes are called metallo-enzymes.

- **Isoenzymes (Isozymes):** At one time it was believed that an organism has only a single enzyme for a given step of a metabolic reaction. It was later discovered that a substrate may be acted upon by a number of variants of an enzyme producing the same product.

Classes of enzymes based on the substrate they act up on

Enzymes can be classified based on different criteria of which classification based on the substrate they acted up on is the most common (Table 4.1).

Table 4.1. Major classes of Enzymes

S.No.	Type of reaction	Description of reaction	Enzyme class
1.	Oxidation – reduction	Transfer of electrons.	Oxidoreductases
2.	Group transfer	Transfer of a functional group from one molecule to another.	Transferases
3.	Hydrolysis	Cleavage of bonds by the addition of water.	Hydrolases
4.	Nonhydrolytic cleavage	Cleaving/splitting a molecule by nonhydrolytic processes.	Lyases
5.	Isomerization & rearrangements	Rearrangement of atoms to form isomers.	Isomerases
6.	Ligation using energy from ATP	Formation of Carbon and other bonds with energy from ATP.	Ligases

(Source: Concepts in Biochemistry; Rodney Boyer)

4.1.3 Mechanisms of enzyme action

Mechanisms of enzyme catalysis vary, but are all similar in principle to other types of chemical catalysis in that the crucial factor is a reduction of energy barrier(s) separating the reactants from the products. The reduction of activation energy increases the fraction of reactant molecules that can overcome this barrier and form the product. An important principle is that since they only reduce energy barriers between products and reactants, enzymes always catalyze reactions in both directions, and cannot drive a reaction forward or affect the equilibrium position.

An enzyme attracts substrates to its active site, catalyzes the chemical reaction by which products are formed, and then allows the products to dissociate (separate from the enzyme surface). The combination formed by an enzyme and its substrates is called the **enzyme–substrate complex**. The substrates are attracted to the active site by **electrostatic and hydrophobic forces**, which are called noncovalent bonds because they are physical attractions and not chemical bonds.

Do you recall enzyme models? Discuss on it in detail.

4.1.4 Factors affecting enzymatic activities

The activity of an enzyme is affected by its environmental conditions such as temperature and pH. Changing these alter the rate of reaction caused by the enzyme. In nature, organisms adjust the conditions of their enzymes to produce an optimum rate of reaction, where necessary, or they may have enzymes which are adapted to function well in extreme conditions where they live.

Temperature

Increasing temperature increases the **kinetic energy** that molecules possess. In a fluid, this means that there are more random collisions between molecules per unit time. Since enzymes catalyse reactions by randomly colliding with substrate molecules, increasing temperature increases the rate of reaction, forming more product.

However, increasing temperature also increases the **vibrational energy** that molecules have, specifically (in this case enzyme molecules), which puts strain (damage) on the bonds that hold them together. As temperature increases, more bonds, especially the weaker hydrogen and ionic bonds, will break as a result of this strain. Breaking bonds within the enzyme will cause the **active site** to change shape. This change in shape means that the Active Site is less complementary to the shape of the Substrate, so that it is less likely to catalyse the reaction. Eventually, the enzyme will become denatured and will no longer function. The temperature at which the maximum rate of reaction occurs is called the enzyme's Optimum Temperature. This is different for different enzymes.

Activity

1. Graphically, show the relationship between enzyme activity and temperature.

2. What is the optimum temperature for most enzymes in the human body?

pH - Acidity and Basicity

pH is a measure of the hydrogen ion (H^+) concentration, and therefore a good indicator of the hydroxide ion (OH^-) concentration. Lower pH values mean higher H^+ concentrations and lower OH^- concentrations. H^+ and OH^- ions are charged and therefore interfere with hydrogen and ionic bonds that hold together an enzyme, since they will be attracted or repelled by the charges created by the bonds. This interference causes a change in shape of the enzyme, and importantly, its active site.

Different enzymes have different optimum pH values. This is the pH value at which the bonds within them are influenced by H+ and OH- ions in such a way that the shape of their active site is the most complementary to the shape of their substrate. At the optimum pH, the rate of reaction is at an optimum. Any change in pH above or below the optimum will quickly cause a decrease in the rate of reaction, since more of the enzyme molecules will have active sites whose shapes are not (or at least are less) complementary to the shape of their substrate.

Small changes in pH above or below the optimum do not cause a permanent change to the enzyme, since the bonds can be reformed. However, extreme changes in pH can cause enzymes to denature and permanently lose their function. Enzymes in different locations of our body have different optimum pH values since their environmental conditions may be different. For example, the enzyme pepsin functions best at around pH-2 and is found in the stomach, which contains hydrochloric acid.

Because enzymes are sensitive to changes in acidity, most living systems are highly buffered; i.e., they have mechanisms that enable them to maintain a constant acidity.

Activity

What do you know about a buffer and its importance in the body of organisms?

Substrate and enzyme concentration

Changing the enzyme and substrate concentrations affect the rate of reaction of an enzyme-catalysed reaction. Controlling these factors in a cell is one way that an organism regulates its enzyme activity and so its metabolism. Changing the concentration of a substance only affects the rate of reaction if it is the limiting factor. If it is the limiting factor, increasing concentration will increase the rate of reaction up to a point, after which any increase will not affect the rate of reaction. This is because it will no longer be the limiting factor and another factor will be limiting the maximum rate of reaction. As a reaction proceeds, the rate of reaction will decrease, since the substrate will get used up.

Substrate concentration

Increasing substrate concentration increases the rate of reaction. This is because more substrate molecules will be colliding with enzyme molecules, so more product will be formed. However, after a certain concentration, any increase will have no effect on the rate of reaction, since substrate concentration will no longer be the limiting factor. The enzymes will effectively become saturated, and will be working at their maximum possible rate.

Enzyme concentration

Increasing enzyme concentration will increase the rate of reaction, as more enzymes will be colliding with substrate molecules. However, this too will only have an effect up to a certain concentration, where the enzyme concentration is no longer the limiting factor.

Activity
✓ *Show graphically the relationships between enzyme activity and substrate concentration as well as enzyme concentration*

4.1.5 Enzyme inhibitors

Enzyme activity can be inhibited in various ways. Inhibition could be reversible or irreversible.

Reversible inhibition

Competitive inhibition: occurs when molecules very similar to the substrate molecules bind to the active site and prevent binding of the actual substrate. Penicillin, for example, is a competitive inhibitor that blocks the active site of an enzyme that many bacteria use to construct their cell walls.

Noncompetitive inhibition: occurs when an inhibitor binds to the enzyme at a location other than the active site. In some cases of noncompetitive inhibition, the inhibitor is thought to bind to the enzyme in such a way as to physically block the normal active site. In other instances, the binding of the inhibitor is believed to change the shape of the enzyme molecule, thereby deforming its active site and preventing it from reacting with its substrate. This latter type of noncompetitive inhibition is called **allosteric inhibition**; the place where the inhibitor binds to the enzyme is called the *allosteric site*. Frequently, an end-product of a metabolic pathway serves as an allosteric inhibitor on an earlier enzyme of the pathway. This inhibition of an enzyme by a product of its pathway is a form of **negative feedback**.

Activators: Allosteric control can involve stimulation of enzyme action as well as inhibition. An activator molecule can be bound to an allosteric site and induce a reaction at the active site by changing its shape to fit a substrate that could not induce the change by itself. Common activators include hormones and the products of earlier enzymatic reactions. Allosteric stimulation and inhibition allow production of energy and materials by the cell when they are needed and inhibit production when the supply is adequate.

Irreversible inhibition

Irreversible inhibitors usually covalently modify an enzyme, and inhibition can therefore not be reversed. Irreversible inhibitors often contain reactive functional groups. Irreversible inhibition is different from reversible enzyme inactivation. Irreversible inhibitors are generally specific for one class of enzyme and do not inactivate all proteins; they do not function by destroying protein structure but by specifically altering the active site of their target

Activity

1. Describe other types of inhibition.

2. Relate the concept of irreversible enzyme inhibition to drug discovery and food poisoning.

3. Explain how painkillers like ibuprofen relieved you from pain.

4. What is the difference between endothermic and exothermic reaction?

5. What is meant by a catalyst?

6. Why are several enzymes needed in a typical metabolic path ways?

7. Which of the three (coenzyme, cofactor, apoenzyme) is a protein?

8. Describe three factors that that influences enzymatic activity.

4.2 Bioenergetics and biosynthesis

4.2.1 Cellular respiration

Most living organisms obtain energy by breaking down organic molecules (catabolism) during cellular respiration. The function of cellular respiration is to harvest electrons from carbon compounds, such as glucose, and use that energy to make Adenosine Tri Phosphate (ATP). ATP is used to provide immediate energy for cells to do work. This catabolic process can be divided into 3 phases.

> **Phase I** - Breakdown of large complex biomolecules like polysaccharides, proteins and lipids into their respective building blocks (**hydrolysis**). The chemical reactions occurring during this stage do not release much energy.
>
> **Phase II** - These building blocks are usually oxidized to a common intermediate, acetyl - CoA. Additionally, pyruvate or other citric acid cycle intermediates may also be formed (in glycolysis and other pathways).
>
> **Phase III** – This consists of the citric acid cycle (i.e. oxidation of acetyl - CoA to CO_2, formation of NADH and $FADH_2$) followed by electron transport and oxidative phosphorylation. Energy released by electron transport to O_2 is coupled to ATP synthesis. This cycle is responsible for the release of much energy (TCA cycle and ETC).

Cellular respiration occurs in two main parts: glycolysis and aerobic respiration. The first stage, glycolysis, is an anaerobic process. Anaerobic metabolic processes do not require oxygen. Aerobic respiration includes the Krebs cycle and electron transport chain and is an aerobic process. Aerobic metabolic processes require oxygen.

1.10.1.1 Glycolysis: anaerobic respiration

Glucose is a key metabolite in metabolism. Various pathways that are concerned with the utilization, storage, and regeneration of glucose exist. Glycogen is a polymeric storage form of glucose in human and it is most abundant in the liver and in striated muscle, although some is found in other tissues also. Glycogen is synthesized when glucose supply is high, and its degradation helps to maintain the blood glucose level when we are fasting. When glycogen is depleted, more glucose is synthesized from scratch in gluconeogenesis. This pathway’s most important substrates are amino acids, which are obtained either from a protein-rich diet-for example, during fasting on meat exclusively-or, during starvation, from breakdown of cellular protein, mainly in skeletal muscle. Gluconeogenesis occurs in the liver and in the kidneys.

Self test

1. Define terms (glycolysis and gluconeogenesis)
2. Why glucose is more preferred by cells for respiration than other carbohydrates/lipids?
3. How is anaerobic respiration differing from aerobic respiration?
4. What are the three basic metabolic stages in respiration?

The first step in the degradation of glucose is glycolysis, which breaks down glucose to pyruvate. The main purpose of glycolysis is the generation of energy (ATP). A modest amount of ATP is produced in glycolysis directly, but much more ATP is formed downstream of glycolysis through the complete oxidation of pyruvate. Glycolysis is the most common pathway for glucose degradation to pyruvate and is found in animals, plants and microorganism. This pathway is used by anaerobic as well as aerobic organisms. The process takes place in the cytoplasm of prokaryotes and eukaryotes and does not require oxygen. Under aerobic conditions, most of the pyruvate formed in glycolysis undergoes complete oxidative degradation to CO_2 and H_2O.

Pyruvate intended for complete degradation is transported to the mitochondria, where it is decarboxylated to acetyl-CoA by pyruvate dehydrogenase. Acetyl-CoA is completely degraded in the citric acid cycle (or tricarboxylic acid cycle; TCA cycle for short). The "H_2" that is produced here is not gaseous but bound to co-substrates, as NADH and $FADH_2$, which is subsequently oxidized in the respiratory chain.

If glucose is available in excess of immediate needs and glycogen is already stocked up to capacity, it will still be broken down by glycolysis and pyruvate dehydrogenase to acetyl-CoA. However, acetyl-CoA will then not be oxidized, but it will instead be used for fatty acid synthesis; the fatty acids are converted to triacylglycerol, and this occur in the cytosol of cells in the liver and fat tissue.

Activity
1. Which phases are regarded as the preparatory (or investment) phase? Why?
2. What is the purpose of each step?
3. What is the fate of pyruvate?

Glycolysis involves ten enzymatic reactions as described below.

The first five are preparatory phases or investment phase. Here, glucose is phosphorylated, rearranged and phosphorylated again, with the two phosphate groups coming from ATP.

1. The phosphorylation of glucose at carbon-6 by hexokinase forming glucose 6-phosphate (G6P).
    - This reaction consumes ATP, but it acts to keep the glucose concentration low, promoting continuous transport of glucose into the cell through the plasma membrane transporters. In addition, it blocks the glucose from leaking out – the cell lacks transporters for G6P, and free diffusion out of the cell is prevented due to the charged nature of G6P. Glucose may alternatively be formed from the phosphorolysis or hydrolysis of intracellular starch or glycogen.
    - In animals, an isozyme of hexokinase called glucokinase is also used in the liver, has a much lower affinity for glucose, and differs in regulatory properties. The different substrate affinity and alternate regulation of this enzyme are a reflection of the role of the liver in maintaining blood sugar levels.
2. The conversion of glucose-6-phosphate(G6P) to fructose-6-phosphate(F6P) by phosphohexose isomerase
    - The change in structure is an isomerization, in which the G6P has been converted to F6P. This reaction is freely reversible under normal cell conditions. However, it is often driven forward because of a low concentration of F6P, which is constantly consumed during the next step of glycolysis. Under conditions of high F6P concentration, this reaction readily runs in reverse. This phenomenon can be explained through Le Chatelier's Principle, "Isomerization to a keto sugar is necessary for carbanion(negative charge of carbon that is stable) stabilization in the fourth reaction step (below)".

3. The phosphorylation of fructose-6-phosphate to the 1,6-bisphosphate by phosphofructokinase,
   - The energy expenditure of another ATP in this step is justified in 2 ways: The glycolytic process (up to this step) becomes irreversible, and the energy supplied destabilizes the molecule. Because the reaction catalyzed by Phosphofructokinase 1 (PFK-1) is coupled to the hydrolysis of ATP (an energetically favorable step) it is, in essence, irreversible, and a different pathway must be used to do the reverse conversion during gluconeogenesis. *This makes the reaction a key regulatory point. This is also the rate-limiting step.*
   - The second phosphorylation event is necessary to allow the formation of two charged groups (rather than only one) in the subsequent step of glycolysis, ensuring the prevention of free diffusion of substrates out of the cell.
   - The same reaction can also be catalyzed by pyrophosphate-dependent phosphofructokinase (PFP or PPi-PFK), which is found in most plants, some bacteria, archea, and protists, but not in animals. This enzyme uses pyrophosphate (PPi) as a phosphate donor instead of ATP. It is a reversible reaction, increasing the flexibility of glycolytic metabolism.
4. The cleavage of fructose-1,6-bisphosphate by aldolase. This yields two different products, dihydroxyacetone phosphate and glyceraldehyde-3-phosphate,
   - Destabilizing the molecule in the previous reaction allows the hexose ring to be split by aldolase into two triose sugars: dihydroxyacetone phosphate (a ketose), and glyceraldehyde 3-phosphate (an aldose). There are two classes of aldolases: class I aldolases, present in animals and plants, and class II aldolases, present in fungi and bacteria; the two classes use different mechanisms in cleaving the ketose ring.
   - Electrons delocalized in the carbon-carbon bond cleavage associate with the alcohol group. The resulting carbanion is stabilized by the structure of the carbanion itself via resonance charge distribution and by the presence of a charged ion prosthetic group.
5. The isomerization of dihydroxyacetone phosphate to a second molecule of glyceraldehyde-3-phosphate by triose phosphate isomerase,

- Triosephosphate isomerase rapidly interconvert dihydroxyacetone phosphate with glyceraldehyde 3-phosphate (GADP) that proceeds further into glycolysis. This is advantageous, as it directs dihydroxyacetone phosphate down the same pathway as glyceraldehyde 3-phosphate, simplifying regulation.

Remember!!

The rest five are pay-off phases which are characterized by a net gain of the energy-rich molecules ATP and NADH. Since glucose leads to two triose sugars in the preparatory phase, each reaction in the pay-off phase occurs twice per glucose molecule. This yields 2 NADH molecules and 4 ATP molecules, leading to a net gain of 2 NADH molecules and 2 ATP molecules from the glycolytic pathway per glucose. Along the way, the two molecules are rearranged into pyruvate.

6. The dehydrogenation and concomitant phosphorylation of glyceraldehyde-3-phosphate to 1,3-bis-phosphoglycerate by glyceraldehyde-3-phosphate dehydrogenase,
   - The aldehyde groups of the triose sugars are oxidised, and inorganic phosphate is added to them, forming 1, 3-bisphosphoglycerate.
   - The hydrogen is used to reduce two molecules of NADH, a hydrogen carrier, to give NADH + H^+ for each triose.
   - Hydrogen atom balance and charge balance are both maintained because the phosphate (Pi) group actually exists in the form of a hydrogen phosphate anion (HPO_4^{2-}), which dissociates to contribute the extra H ion and gives a net charge of -3 on both sides.

Note that: *Arsenate (AsO_4^{3-}), an anion similar to inorganic phosphate may replace phosphate as a substrate to form 1-arseno-3-phosphoglycerate. This, however, is unstable and readily hydrolyzes to form 3-phosphoglycerate, the intermediate in the next step of the pathway. As a consequence of bypassing this step, the molecule of ATP generated from 1-3 bisphosphoglycerate in the next reaction will not be made, even though the reaction proceeds. As a result, arsenate is an uncoupler of glycolysis during Arsenic poisoning.*

7. The transfer of the 1-phosphate group from 1,3-bis-phosphoglycerate to ADP by phosphoglycerate kinase, which yields ATP and 3-phosphoglycerate.

- At this step, glycolysis has reached the break-even point: 2 molecules of ATP were consumed, and 2 new molecules have now been synthesized. This step, one of the two substrate-level phosphorylation steps, requires ADP; thus, when the cell has plenty of ATP (and little ADP), this reaction does not occur. Because ATP decays relatively quickly when it is not metabolized, this is an important regulatory point in the glycolytic pathway.
- ADP actually exists as $ADPMg^{-}$, and ATP as $ATPMg^{2-}$, balancing the charges at -5 both sides.

8. The isomerization of 3-phosphoglycerate to 2-phosphoglycerate by phosphoglycerate mutase(PGAM),

***Note that**: PGAM plays an important role in coordinating glycolysis and anabolic activity to promote cancer cell proliferation. It is suggested that even under aerobic conditions cancer cells can show a high rate of glycolysis and increased production of lactate, generating ATP faster than normal cells. However, to obtain sufficient ATP and carbons to generate biomass [nucleotides, amino acids, lipids and nicotinamide adenine dinucleotide phosphate (NADPH)] cancer cells must uptake more glucose than normal cells to meet the metabolic requirements of rapid cell proliferation owing to the low efficiency of glycolysis.*

9. The dehydration of 2-phosphoglycerate to phosphoenolpyruvate by enolase.
10. The transfer of the phosphate group from phosphoenolpyruvate to ADP by pyruvate kinase, to yield a second molecule of ATP.

- A final substrate-level phosphorylation now forms a molecule of pyruvate and a molecule of ATP by means of the enzyme pyruvate kinase. This serves as an additional regulatory step, similar to the phosphoglycerate kinase step.

*Most, but not all reactions in glycolysis are reversible; this can be indicated by different arrows (**Fig**. 4.1). Because it contains several irreversible reactions, the pathway as a whole is also irreversible. However, alternate routes exist that bypass the irreversible reactions and allow glucose to be synthesized from pyruvate.*

Biochemical logic for the presence of regulatory steps

The existence of more than one point of regulation indicates that intermediates between those points enter and leave the glycolysis pathway by other processes. For example, in the first regulated step, hexokinase converts glucose into glucose-6-phosphate. Instead of continuing through the glycolysis pathway, this intermediate can be converted into glucose storage molecules, such as glycogen or starch. The reverse reaction, breaking down, e.g., glycogen, produces mainly glucose-6-phosphate; very little free glucose is formed in the reaction. The glucose-6-phosphate so produced can enter glycolysis after the first control point.

In the second regulated step (the third step of glycolysis), phosphofructokinase converts fructose-6-phosphate into fructose-1, 6-bisphosphate, which then is converted into glyceraldehyde-3-phosphate and dihydroxyacetone phosphate. The dihydroxyacetone phosphate can be removed from glycolysis by conversion into glycerol-3-phosphate, which can be used to form triglycerides. Conversely, triglycerides can be broken down into fatty acids and glycerol; the latter, in turn, can be converted into dihydroxyacetone phosphate, which can enter glycolysis after the second control point.

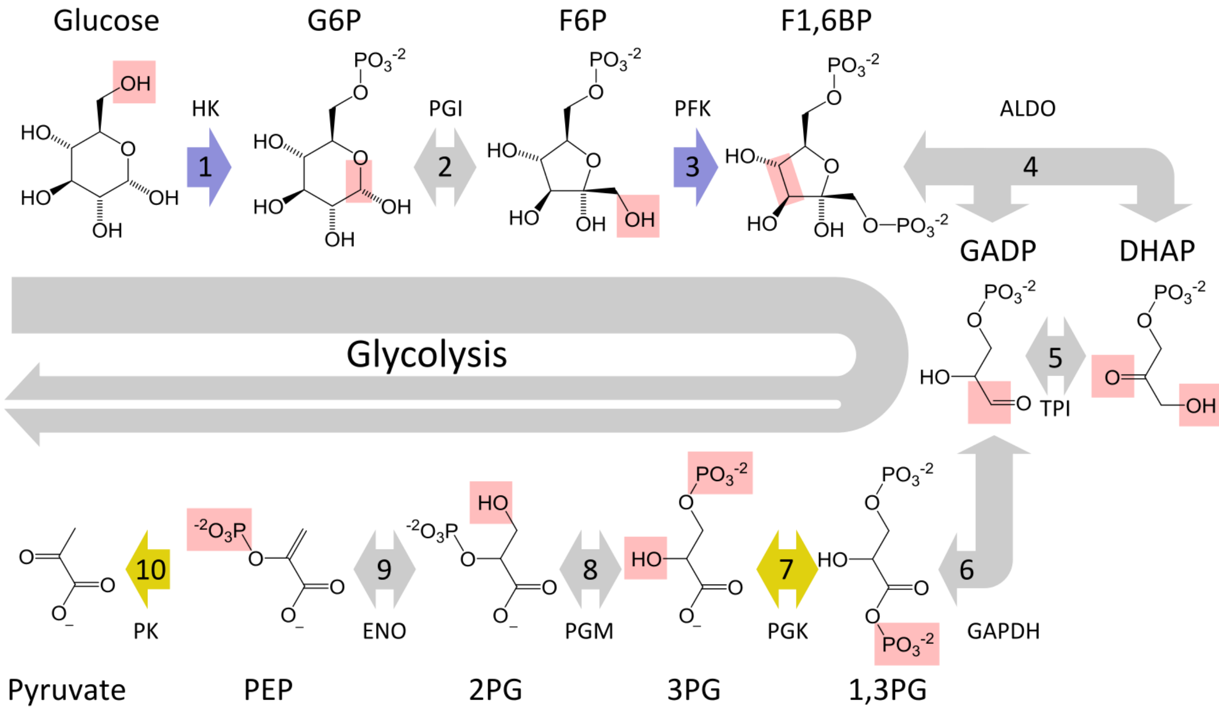


Fig: 4.1. Glycolysis steps

Activity

1. Relate regulation of the rate limiting enzymes to homeostasis and biosynthesis?

2. Name and describe diseases related to failure in one or more of the steps of glycolysis?

3. Write the overall reactions of glycolysis.

4. Which of the following are *products of cellular respiration?*

A. Glucose; B. Pyruvate; C. Carbon dioxide; D. Acetyl CoA E.all except A

1.10.1.2 TCA cycle and ETC: Aerobic respiration

One fate of pyruvate is that it enters to TCA cycle for complete oxidation. But there are intermediate processes that convert pyruvate to a acetyl coA. The enzyme complex converts pyruvate into Acetyl-CoA by the following chemical changes:

- Decarboxylation of pyruvate (loss of CO_2)
- Formation of acetyl group
- Linkage of acetyl group to coenzyme A forming acetyl - CoA.

The Tricarboxylic Acid (TCA) Cycle (Phase III)

The TCA cycle also called Krebs or Citric acid cycle, is considered as central pathway of aerobic metabolism, as it serves two purposes-bioenergetics and biosynthesis:

1. **Bioenergetic** - The cycle carries out complex degradation of acetyl group in acetyl - CoA to CO_2, resulting in release of energy (ATP or GTP) and reducing power (NADH and $FADH_2$).

TCA oxidizes two-carbon units, producing two molecules of CO_2, one molecule of GP, and high-energy electrons in the form of NADH and $FADH_2$.

Steps of the Krebs cycle

Prior to the Krebs cycle, pyruvate first reacts with coenzymeA (CoA) to form a 2-carbon intermediate called acetyl CoA. At the same time, carbon dioxide is released and NAD is converted to NADH. Acetyl CoA then moves to the mitochondrial matrix. The reaction results in the production of two carbon dioxide molecules and two NADH.

- The Krebs cycle begins with acetyl CoA combining with a 4-carbon compound to form a 6-carbon compound known as citric acid.
- Citric acid is then broken down in the next series of steps, releasing two molecules of carbon dioxide and generating one ATP, three NADH, and one FADH. FAD is another electron carrier similar to NADH and NADPH.

➢ Finally, acetyl CoA and citric acid are generated and the cycle continues.

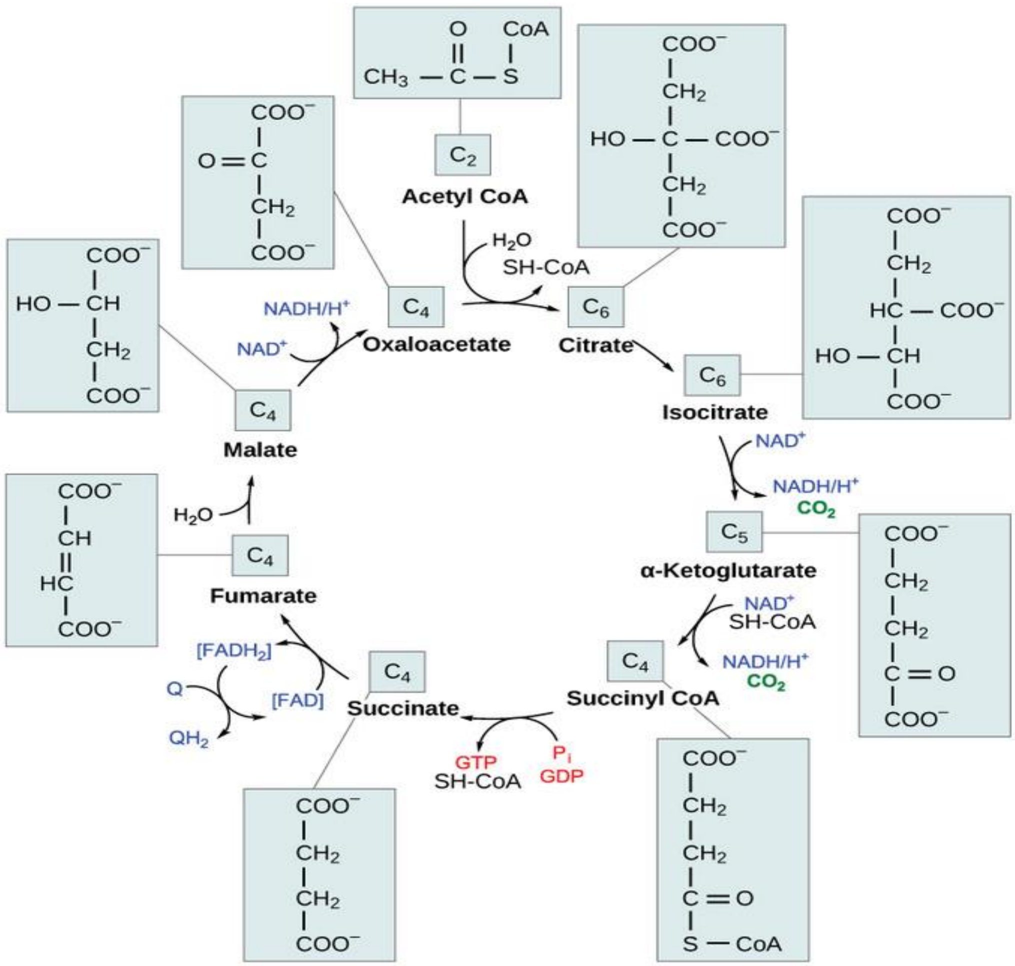


Fig: 4.2. The TCA cycle

Recall that two molecules of pyruvate are formed during glycolysis, resulting in two "turns" of the Krebs cycle for each glucose molecule. The net yield from the Krebs cycle is six carbon dioxide molecules, two ATP, eight NADH, and two $FADH_2$. NADH and $FADH_2$ move on to play a significant role in the next stage of aerobic respiration.

2. **Biosynthesis -** It supplies precursors for several biosynthetic pathways of amino acids, pyrimidines, purines etc.
    - ✓ As already mentioned, the TCA cycle is also an important source of biosynthetic precursors
   - ➢ e.g. α-ketoglutarate and oxaloacetate are used for synthesis of a number of amino acids like glutamic acid, asparatic acid etc.
   - ➢ Succinyl - CoA is used to form porphyrin ring of cytochromes, chlorophyll etc.

- Oxaloacetate can also be converted to phosphoenolpyruvate, which is a precursor of glucose.
- Acetyl - CoA is the starting material for fatty acid biosynthesis.

1.10.1.3 Electron Transport Chain

In aerobic respiration, electron transport is the final step in the break-down of glucose. It also is the point at which most of the ATP is produced. High-energy electrons and hydrogen ions from NADH and $FADH_2$ produced in the Krebs cycle are used to convert ADP to ATP.

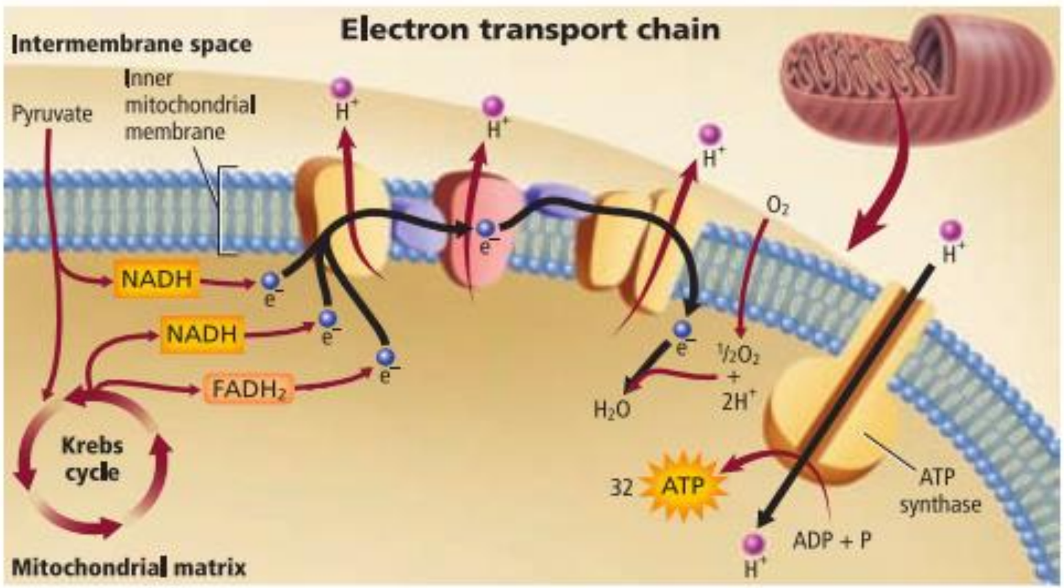


Fig: 4.3. Electron Transport Chain

As shown in **Fig 4.3**., electrons move along the mitochondrial membrane from one protein to another. As NADH and $FADH_2$ electrons, the energy carriers are converted to NADH release and FAD, and H ions are released into the mitochondrial matrix. The H ions are pumped into the mitochondrial matrix across the inner mitochondrial membrane. H ions then diffuse down their concentration gradient back across the membrane and into the matrix through ATP synthase molecules in chemiosmosis. Electron transport and chemiosmosis in cellular respiration are similar to these processes in photosynthesis. Oxygen is the final electron acceptor in the electron transport system in cellular respiration. Protons and electrons are transferred to oxygen to form water.

Activity
1.What is the overall chemical reaction of aerobic reparation?

2. How many ATP molecules are collected during electron transport chain and chemiosmosis from a single glucose?

4.2.2 Biosynthesis

Biosynthesis is a multi-step, enzyme-catalyzed process where substrates are converted into more complex products in living organisms. In biosynthesis, simple compounds are modified, converted into other compounds, or joined together to form macromolecules. This process often consists of metabolic pathways. Some of these biosynthetic pathways are located within a single cellular organelle, while others involve enzymes that are located within multiple cellular organelles. Examples of these biosynthetic pathways include the production of lipid membrane components and nucleotides. Biosynthesis is usually synonymous with anabolism.

The prerequisite elements for biosynthesis include: precursor compounds, chemical energy (e.g. ATP), and catalytic enzymes which may require coenzymes (e.g.NADH, NADPH). These elements create monomers, the building blocks for macromolecules. Some important biological macromolecules include: proteins, which are composed of amino acid monomers joined via peptide bonds, and DNA molecules, which are composed of nucleotides joined via phosphodiester bonds.

Requirements of Biosynthesis

Sometimes all that is required for biosynthesis is for two substances to physically join together to make a new physical substance, which is called a macromolecule.

A very simplified equation for biosynthesis of one form of macromolecule: two substances join together to form a new, more complex substance.

i. **Photosynthesis**

Self-test

1. Define photosynthesis.

2. What is an ultimate source of energy for all life forms?

Energy is transformed all around us every day. Batteries convert chemical energy into electric energy, and radios convert electric energy into the energy carried by sound waves. Similarly, some autotrophs convert light energy into chemical energy through photosynthesis.

The importance of photosynthesis

The processes of all organisms, from bacteria to humans require energy. To get this energy, many organisms access stored energy by eating food. Carnivores eat other animals and herbivores eat plants. But where does the stored energy in food originate? All of this energy can be traced back to the process of photosynthesis and light energy from the sun. Photosynthesis is essential to all life on earth. It is the only biological process that captures energy from outer space (sunlight) and converts it into chemical energy in the form of Glyceraldehyde3-phosphate (G3P), which in turn can be made into sugars and other organic compounds such as proteins, lipids, and nucleic acids. Plants use these compounds in all of their metabolic processes; plants do not need to consume other organisms for food because they build all the molecules they need. Unlike plants, animals need to consume other organisms to consume the molecules they need for their metabolic processes.

The process of photosynthesis

During photosynthesis, molecules in leaves capture sunlight and energize electrons, which are then stored in the covalent bonds of carbohydrate molecules. That energy within those covalent bonds will be released when they are broken during cell respiration. How long lasting and stable are those covalent bonds? The energy extracted today by the burning of coal and petroleum products represents sunlight energy captured and stored by photosynthesis almost 200 million years ago.

Plants, algae, and some bacteria such as cyanobacteria are the only organisms capable of performing photosynthesis. Because they use light to manufacture their own food, they are called photoautotrophs (“self-feeders using light”). Other organisms, such as animals, fungi, and most other bacteria, are termed heterotrophs (“other feeders”) because they must rely on the sugars produced by photosynthetic organisms for their energy needs. A third very interesting group of bacteria synthesize sugars, not by using sunlight’s energy, but by extracting energy from inorganic chemical compounds; hence, they are referred to as chemoautotrophs.

The importance of photosynthesis is not just that it can capture sunlight’s energy. A lizard sunning itself on a cold day can use the sun’s energy to warm up. Photosynthesis is vital because it evolved as a way to store the energy in solar radiation (the"photo" part) as high-energy electrons in the carbon-carbon bonds of carbohydrate molecules (the "synthesis" part).

Those carbohydrates are the energy source that heterotrophs use to power the synthesis of ATP via respiration. Therefore, photosynthesis powers 99 percent of Earth's ecosystems. When a top predator, such as a wolf, preys on a deer, the wolf is at the end of an energy path that went from nuclear reactions on the surface of the sun, to light, to photosynthesis, to vegetation, to deer, and finally to wolf.

Other variant of photosynthesis

Commonly known photosynthetic processes is the one known as oxygenic photosynthesis. The other type is termed as anoxygenic photosynthesis. The general principles of anoxygenic and oxygenic photosynthesis are very similar, but oxygenic photosynthesis is the most common and is seen in plants, algae and cyanobacteria.

During oxygenic photosynthesis, light energy transfers electrons from water (H_2O) to carbon dioxide (CO_2), to produce carbohydrates. In this transfer, the CO_2 is "reduced," or receives electrons, and the water becomes "oxidized," or loses electrons. Ultimately, oxygen is produced along with carbohydrates.

On the other hand, anoxygenic photosynthesis uses electron donors other than water. The process typically occurs in bacteria such as purple bacteria and green sulfur bacteria, which are primarily found in various aquatic habitats.

Anoxygenic photosynthesis does not produce oxygen. What is produced depends on the electron donor. For example, many bacteria use the bad-eggs-smelling gas hydrogen sulfide, producing solid sulfur as a byproduct.

Though both types of photosynthesis are complex, multistep affairs, the overall process can be neatly summarized as a chemical equation.

Oxygenic photosynthesis is written as follows:

$$\boxed{6CO_2 + 12H_2O + \text{Light Energy} \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O}$$

Similarly, the various anoxygenic photosynthesis reactions can be represented as a single generalized formula:

$$CO2 + 2H_2A + \text{Light Energy} \rightarrow [CH_2O] + 2A + H_2O$$

The letter A in the equation is a variable and H_2A represents the potential electron donor. For example, A may represent sulfur in the electron donor hydrogen sulfide (H_2S).

4.2.2.1The photosynthetic apparatus

Self test
1. What cellular components are essential to photosynthesis?
2. why plant leaves vary in color?

Plastids

Photosynthetic eukaryotic organisms contain organelles called plastids in their cytoplasm. Plastids generally contain pigments or can store nutrients. Colorless and nonpigmented leucoplasts store fats and starch, while chromoplasts contain carotenoids and chloroplasts contain chlorophyll.

Photosynthesis occurs in the chloroplasts; specifically, in the grana and stroma regions. The grana is the innermost portion of the organelle; a collection of disc-shaped membranes, stacked into columns like plates. The individual discs are called thylakoids. It is here that the transfer of electrons takes place. The empty spaces between columns of grana constitute the stroma.

Chloroplasts are similar to mitochondria, the energy centers of cells, in that they have their own genome, or collection of genes, contained within circular DNA. These genes encode proteins essential to the organelle and to photosynthesis. Like mitochondria, chloroplasts are also thought to have originated from primitive bacterial cells through the process of endosymbiosis.

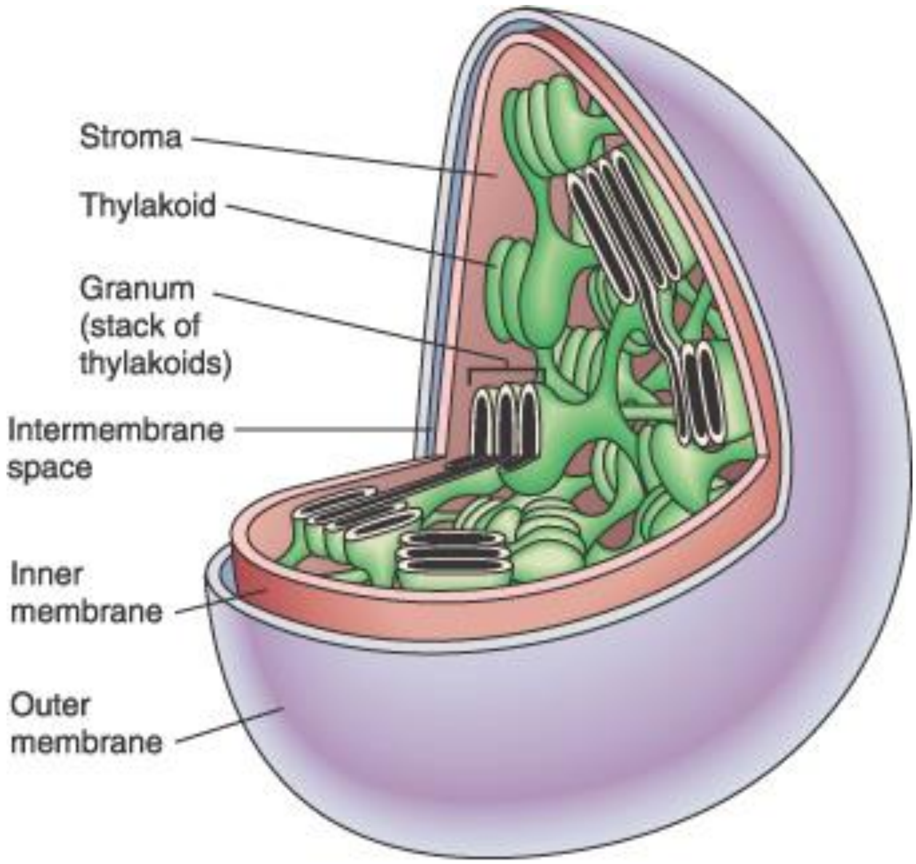


Fig: 4.4. Structure of chloroplast

Pigments

Pigments are molecules that bestow color on plants, algae and bacteria, but they are also responsible for effectively trapping sunlight. Pigments of different colors absorb different wavelengths of light. Below are the three main groups.

- **Chlorophylls**: These green-colored pigments are capable of trapping blue and red light. Chlorophylls have three subtypes, dubbed chlorophyll a, chlorophyll b and chlorophyll c. There is also a bacterial variant aptly named bacteriochlorophyll, which absorbs infrared light. This pigment is mainly seen in purple and green bacteria, which perform anoxygenic photosynthesis.

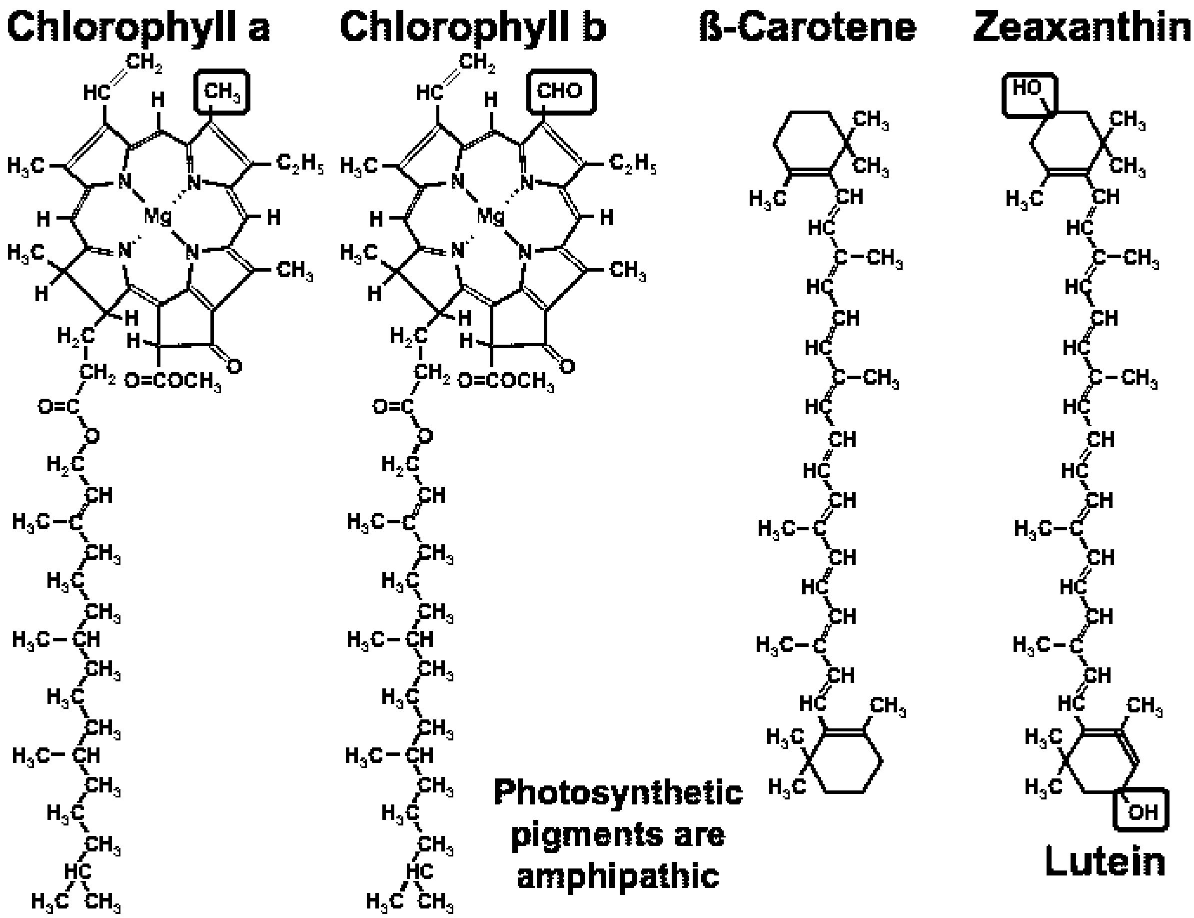


Fig: 4.5. Basic structures of major photosynthetic pigments

- **Carotenoids:** These red, orange or yellow-colored pigments absorb bluish-green light. Examples of carotenoids are xanthophyll (yellow) and carotene (orange) from which carrots get their color.
- **Phycobilins**: These red or blue pigments absorb wavelengths of light that are not as well absorbed by chlorophylls and carotenoids. They are seen in cyanobacteria and red algae.

Antennae

Pigment molecules are associated with proteins, which allow them the flexibility to move toward light and toward one another. A large collection of 100 to 5,000 pigment molecules constitutes antennae. These structures effectively capture light energy from the sun, in the form of photons.

Ultimately, light energy must be transferred to a pigment-protein complex that can convert it to chemical energy, in the form of electrons. In plants, for example, light energy is transferred to chlorophyll pigments. The conversion to chemical energy is accomplished when a chlorophyll pigment expels an electron, which can then move on to an appropriate recipient.

Reaction centers

The pigments and proteins, which convert light energy to chemical energy and begin the process of electron transfer, are known as reaction centers.

4.2.2.2 The photosynthetic process

The reactions of plant photosynthesis are divided into those that require the presence of sunlight and those that do not. Both types of reactions take place in chloroplasts: light-dependent reactions in the thylakoid and light-independent reactions in the stroma.

Light-dependent reactions (also called light reactions): When a photon of light hits the reaction center, a pigment molecule such as chlorophyll releases an electron.

How does this generate energy?

The released electron manages to escape by traveling through an electron transport chain, which generates the energy needed to produce ATP (adenosine triphosphate, a source of chemical energy for cells) and NADPH. The "electron hole" in the original chlorophyll pigment is filled by taking an electron from water. As a result, oxygen is released into the atmosphere.

Light-independent reactions (also called dark reactions and known as the Calvin cycle): Light reactions produce ATP and NADPH, which are the rich energy sources that drive dark reactions.

Although NADPH and ATP provide cells with large amounts of energy, these molecules are not stable enough to store chemical energy for long periods of time. Thus, there is a second phase of photosynthesis called the Calvin cycle in which energy is stored in organic molecules such as glucose.

Three chemical reaction steps make up the Calvin cycle: carbon fixation, reduction and regeneration. These reactions use water and catalysts. The carbon atoms from carbon dioxide are "fixed," when they are built into organic molecules that ultimately form three-carbon sugars. These sugars are then used to make glucose or are recycled to initiate the Calvin cycle again.

- ✓ In the first step of the Calvin cycle called carbon fixation, six carbon dioxide (CO) molecules combine with six 5-carbon compounds to form twelve 3-carbon molecules called 3-phosphoglycerat (3-PGA). The joining of carbon dioxide with other organic molecules is called carbon fixation.
- ✓ In the second step, the chemical energy stored in ATP and NADPH is transferred to the 3-PGA molecules to form high-energy molecules called glyceraldehyde 3-phosphates (G3P). ATP supplies the phosphate groups for forming G3P molecules, while NADPH supplies hydrogen ions and electrons.
- ✓ In the third step, two G3P molecules leave the cycle to be used for the production of glucose and other organic compounds. In the final step of the Calvin cycle, an enzyme called rubisco converts the remaining ten G3P molecules into 5-carbon molecules called ribulose 1, 5-bisphosphates (RuBP). These molecules combine with new carbon dioxide molecules to continue the cycle.

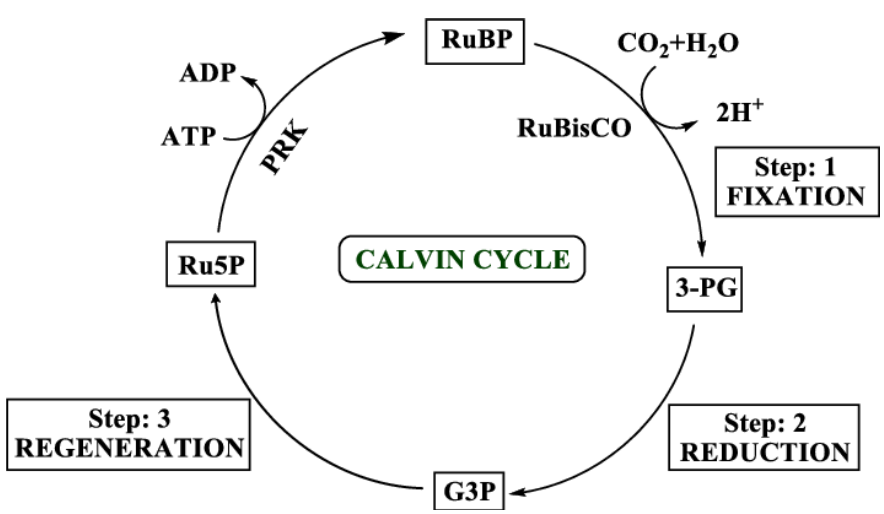


Fig:4.6. Calvin cycle

Because rubisco converts inorganic carbon dioxide molecules into organic molecules that can be used by the cell, it is considered one of the most important biological enzymes. Plants use the sugars formed during the Calvin cycle both as a source of energy and as building blocks for complex carbohydrates, including cellulose, which provides structural support for the plant.

Alternative Pathways

The environment in which an organism lives can impact the organism's ability to carry out photosynthesis. Environments in which the amount of water or carbon dioxide available is insufficient can decrease the ability of a photosynthetic organism to convert light energy into chemical energy. For example, plants in hot, dry environments are subject to excessive water loss that can lead to decreased photosynthesis. Many plants in extreme climates have altered native photosynthesis pathways to maximize energy conversion.

C4 plants one adaptive pathway that helps plants maintain photosynthesis while minimizing water loss is called the C4 pathway. The C4 pathway occurs in plants such as sugar cane and corn. These plants are called C4 plants because they fix carbon dioxide into four-carbon compounds instead of three-carbon molecules during the Calvincycle. C4 plants also have significant structural modifications in the arrangement of cells in the leaves. In general, C4 plants keep their stomata (plant cell pores) closed during hot days, while the four carbon compounds are transferred to special cells where CO_2 enters the Calvin cycle. This allows for sufficient carbon dioxide uptake, while simultaneously minimizing water loss.

CAM plants another adaptive pathway used by some plants to maximize photosynthetic activity is called crassulacean acid metabolism (CAM photosynthesis). The CAM pathway occurs in water conserving plants that live in deserts, salt marshes, and other environments where access to water is limited. CAM plants, such as cacti, orchids, and the pineapple allow carbon dioxide to enter the leaves only at night, when the atmosphere is cooler and more humid. At night, these plants fix carbon dioxide into organic compounds. During the day, carbon dioxide is released from these compounds and enters the Calvin cycle. This pathway Also allows for sufficient carbon dioxide uptake, while minimizing water loss.

Scientific Tips!!

Photosynthesis in the future

Photosynthetic organisms are a possible means to generate clean-burning fuels such as hydrogen or even methane. Recently, a research group at the University of Turku in Finland, tapped into the ability of green algae to produce hydrogen. Green algae can produce hydrogen for a few seconds if they are first exposed to dark, anaerobic (oxygen-free) conditions and then exposed to light. The team devised a way to extend green algae's hydrogen production for up to three days, as reported in their 2018 study published in the journal Energy and Environmental Science.

Scientists have also made advances in the field of artificial photosynthesis. A group of researchers from the University of California, Berkeley, developed an artificial system to capture carbon dioxide using nanowires, or wires that are a few billionths of a meter in diameter. The wires feed into a system of microbes that reduce carbon dioxide into fuels or polymers by using energy from sunlight. The team published its design in 2015 in the journal Nano Letters.

In 2016, members of this same group published a study in the journal Science that described another artificial photosynthetic system in which specially engineered bacteria were used to create liquid fuels using sunlight, water and carbon dioxide. In general, plants are only able to harness about one percent of solar energy and use it to produce organic compounds during photosynthesis. In contrast, the researchers' artificial system was able to harness 10 percent of solar energy to produce organic compounds.

Continued research of natural processes, such as photosynthesis, aids scientists in developing new ways to utilize various sources of renewable energy. Seeing as sunlight, plants and bacteria are all ubiquitous, tapping into the power of photosynthesis is a logical step for creating clean-burning and carbon-neutral fuels.

4.3 Metabolic disorders, diagnosis and treatments

Self-test
1. What are the risk factors for metabolic disorders?
2. How are metabolic disorders treated?

Metabolism is the breaking down of food to its simpler components: proteins, carbohydrates (or sugars), and fats. Metabolic disorders occur when these normal processes become disrupted. Disorders in metabolism can be inherited, in which case they are also known as inborn errors of metabolism, or they may be acquired during your lifetime.

Inherited metabolic disorders

Inherited metabolic disorders are one cause of metabolic disorders, and occur when a defective gene causes an enzyme deficiency. These diseases, of which there are many subtypes, are known as i**nborn errors of metabolism**. Metabolic diseases can also occur when the liver or pancreas do not function properly.

There are numerous examples of inherited metabolic disorders, which can be classified based on the **type of food-related** building block that they affect, including amino acids (the building block for proteins), carbohydrates, and fatty acids (the building block for fats). Inherited causes of metabolic disorders include:

- **Carbohydrate disorders**; examples include *Diabetes insipidus*, hereditary fructose intolerance, galactosemia, pyruvate metabolism disorders, von Gierke's disease, McArdle disease, Pompe's disease, and Forbes' disease
- **Fatty acid oxidation defects**; examples include Gaucher's disease, Niemann-Pick disease, Fabry's disease, and medium-chain acyl-coenzyme A dehydrogenase (MCAD) deficiency
- **Amino acid disorders**; examples include Tay-Sachs disease, phenylketonuria, tyrosinemia, maple syrup urine disease, and homocystinuria
- Acid-base imbalance, Disorders of calcium metabolism, DNA repair-deficiency disorders, Iron metabolism disorders, Mitochondrial diseases, Phosphorus metabolism disorders, Malabsorption syndromes, Water-electrolyte imbalance are some of the disorders associated with metabolism.

Other causes of metabolic disorders

Metabolic disorders can be due to other factors, such as a combination of inherited and environmental factors. Some of the conditions that can cause metabolic disorders include:

- Alcohol abuse, Diabetes (chronic disease that affects your body's ability to use sugar for energy)
- Diuretic abuse, Gout (type of arthritis caused by a buildup of uric acid in the joints)
- Ingestion of poison or toxins, including excessive aspirin, bicarbonate, alkali, ethylene glycol, or methanol
- Kidney failure, Pneumonia, respiratory failure, or collapsed lung
- Sepsis (life-threatening bacterial blood infection)

4.3.1. Risk factors of metabolic disorders

A number of factors increase the risk of developing metabolic disorders. Not all people with risk factors will get metabolic disorders. Risk factors for metabolic disorders include:

- Certain chronic medical conditions, such as lung or kidney disease (includes any type of kidney problem, such as kidney stones, kidney failure and kidney anomalies) and Diabetes (it is more likely to have metabolic syndrome if a person had diabetes during pregnancy (gestational diabetes) or if he/she have a family history of type 2 diabetes.
- Family history of genetic metabolic disorder.
- Race and ethnicity: people with African, Hispanic, First Nations, Asian, and Pacific Islander backgrounds are at higher risk than whites for type 2 diabetes.
- HIV/AIDS and other diseases; the risk of metabolic syndrome is higher if a person ever had nonalcoholic fatty liver disease, polycystic ovary syndrome or sleep apnea
- Age- the risk of metabolic syndrome increases with age.
- Obesity and lack of exercise: carrying too much weight, especially in your abdomen, increases your risk of metabolic syndrome
- Hormone imbalance: a hormone disorder such as polycystic ovary syndrome (PCOS), a condition in which the female body produces too much of certain hormones, is linked with metabolic syndrome.
- Insulin resistance: a situation in which a body cannot use insulin properly.

4.3.2 Diagnosis of metabolic disorders

Metabolic syndrome is more effectively diagnosed by testing different blood markers (specific markers of insulin resistance), obesity (especially abdominal obesity), high blood pressure, and lipid abnormalities. Specifically, metabolic syndrome is diagnosed if **any three of the following five markers** are present:

- Elevated waist circumference: 40 inches or more for men; 35 inches or more for women
- Elevated triglycerides: 150 mg/dL or higher
- Reduced high-density lipoprotein (HDL) levels (AKA "good" cholesterol): less than 40 mg/dL in men; less than 50 mg/dL in women
- Elevated blood pressure: 130/85 mm Hg or higher or are already taking blood pressure medications
- Elevated fasting glucose: 100 mg/dL or higher or are already taking glucose-lowering medications

4.3.3 Treatments of metabolic disorders

The treatment approach for metabolic disorders depends on the specific disorder. Inborn errors of metabolism (inherited metabolic disorders) are often treated with nutritional counseling and support, periodic assessment, physical therapy, and other supportive care options. Multiple treatment options are available for inherited metabolic disorders and examples include: bone marrow transplantation, enzyme replacement therapy in selected patients, gene therapy in selected patients, medications to reduce symptoms, such as pain or low blood sugar, mineral supplementation, nutritional counseling, surgery to relieve pain or symptoms, vitamin supplementation and etc.

Acquired metabolic disorder treatment will include normalizing the metabolic balance by both reversing the cause and administering medications.

Potential complications of metabolic disorders

Complications of untreated metabolic disorders can be serious, even life threatening in some cases. The risk of serious complications can be minimized following the treatment plan designed by health care professional. Complications of metabolic disorders include: organ failure/dysfunction, seizures and tremors, and unconsciousness and coma.

Activity

1. What are the risk factors of metabolic disorders?
2. How are metabolic disorders treated?
3. Write down the common metabolic disorders and their symptoms.

Summary

Phenylketonuria is an example of an inherited metabolic disorder characterized by an inability to break down one of the building blocks of protein, the amino acid phenylalanine.

Type I diabetes, a disease in which the pancreas does not create enough insulin to maintain balanced blood sugar levels, is a metabolic disorder of sugar metabolism.

An example of a metabolic disorder affecting fat metabolism is **Gaucher's disease,** which is characterized by a lack of the of the enzyme glucocerebrosidase.

Unit 5

Genetics and Evolution

Learning Objectives: After completing this chapter, you should be able to:

- ✓ Explain fundamental genetic concepts.
- ✓ Describe the structure and replication of the genetic material and basic aspects of the flow of genetic information from DNA to proteins.
- ✓ Understand mechanisms of flow of genetic information from DNA to proteins (transcription, translation and the genetic code)
- ✓ Describe the phases of mitosis and meiotic in detail and explain the connection between chromosomal behavior in meiosis and Mendelian segregation, independent assortment and linkage
- ✓ Understand the principles of Mendelian inheritance and their extensions (one- and two-locus traits with two or more alleles, gene interactions, sex linkage and linkage) by analyzing inheritance patterns from crosses.
- ✓ Understand the principle of blood grouping and their applications
- ✓ Describe the causes and genetic consequences of mutations
- ✓ Define evolution and describe the different evolutionary theories

Self test

1. Define terms (genetics and evolution)
2. What is the importance of studying genetics?
3. What is the inter-relationship between genetics and evolution?

Genetics forms one of the central pillars of biology and overlaps with many other areas, such as agriculture, medicine, and biotechnology. Since the start of civilization, humankind has recognized the influence of heredity and applied its principles to the improvement of cultivated crops, domestic animals and industrial microbes. Most of the mechanisms of heredity, however, remained a mystery until the 19th century, when genetics as a systematic science began.

Genetics is a field of biology that studies how traits are passed from parents to their offspring. The passing of traits from parents to offspring is known as heredity; therefore, genetics is the study of heredity. The basic components of genetics are DNA, RNA, genes, chromosomes and genetic inheritance. DNA molecules hold all the genetic information for almost all organisms. It provides cells with the information they need to perform tasks that allow an organism to grow, survive and reproduce. A gene is one particular section of a DNA molecule that tells a cell to perform one specific task. Heredity is what makes offspring look like their parents. During reproduction, DNA is replicated and passed from a parent to their offspring. This inheritance of genetic material by offspring influences the appearance and behavior of the offspring. The environment that an organism lives in can also influence how genes are expressed.

Genes (and, thus, the traits they code for) are passed from parent to offspring. From generation to generation, well-understood molecular mechanisms reshuffle, duplicate, and alter genes in a way that produces genetic variation. This variation is the raw material for evolution.

Activities

Students take an inventory of their own easily-observable genetic traits and compare those inventories with other students in groups.

Can you think of a trait you have inherited? How about a trait that you have acquired by learning or tradition?

What inherited traits do you share in common with others? What traits are unique to you?

Learn how common chronic diseases (such as heart disease) run in families and how risk for developing these diseases is influenced by the combined action of several genes.

Identical twins have exactly the same DNA, but they are not exactly alike. Each twin has his or her own personality, talents, likes, and dislikes. There are even diseases that appear in one twin but not in the other, including arthritis, diabetes, autism, schizophrenia, cancer, and many others. What do you think is the reason?

5.1 Basic Principles of Mendelian genetics and patterns of inheritance

Self-test

1. Gregor Mendel's principles of inheritance form the cornerstone of modern genetics and what are they?

2. What were the concepts not included in Mendelian genetics?

3. Where did our knowledge of dominance and recessively first come from?

It is wondering why you are the only one in your family with your grandfather's nose? The way in which traits are passed from one generation to the next, and sometimes skip generations was first explained by Gregor Mendel. By experimenting with pea plant breeding, Mendel developed three principles of inheritance that described the transmission of genetic traits, before anyone knew genes existed. Mendel's insight greatly expanded the understanding of genetic inheritance, and led to the development of new experimental methods.

Traits are passed down in families in different patterns. Pedigrees can illustrate these patterns by following the history of specific characteristics, or phenotypes, as they appear in a family. The inheritance pattern in which traits of generation I has passed down through the family tree is considered dominant, because it is observable in every generation. Thus, every individual who carries the genetic code for this characteristic will show evidence of the characteristic. A characteristic may disappear in one generation, only to reappear in a subsequent one. This pattern of inheritance, in which the parents do not show the phenotype but some of the children do, is considered recessive.

Mendelian inheritance is a type of biological inheritance that follows the principles originally proposed by Gregor Mendel in 1865 and 1866. It was re-discovered in 1900 and popularized by William Bateson. These principles were initially controversial and even rejected by some scholars. When Mendel's theories were integrated with the Boveri–Sutton chromosome theory of inheritance by Thomas Hunt Morgan in 1915, they became the core of classical genetics.

Ronald Fisher combined these ideas with the theory of natural selection in his 1930 book. The genetic theory of natural selection, putting evolution onto a mathematical footing and forming the basis for population genetics within the modern evolutionary synthesis.

Gregor Johann Mendel formulated his idea after conducting simple hybridisation experiments with pea plants (*Pisum sativum*) he had planted in the garden of his monastery. From these experiments, he induced two generalizations which later became known as Mendel's Principles of Heredity or Mendelian inheritance.

Activities
1. Why Mendel choose Pisum sativum for his experimentation? *2. Recall the basic experiments Mendel used to convey his principles of inheritance* *3. What were the major conclusions of Mendel's experiment?*

Mendel's results were largely ignored by the vast majority. Although they were not completely unknown to biologists of the time, they were not seen as generally applicable, even by Mendel himself, who thought they only applied to certain categories of species or traits. In 1900, however, his work was "re-discovered" by some scientist. Regardless, the "re-discovery" made Mendelism an important but controversial theory.

Mendel's findings allowed some scientists to predict the expression of traits on the basis of mathematical probabilities. An important aspect of Mendel's success can be traced to his decision to start his crosses only with plants he demonstrated were true-breeding. He only measured discrete (binary) characteristics, such as color, shape, and position of the seeds, rather than quantitatively variable characteristics. He expressed his results numerically and subjected them to statistical analysis.

Mendel's conclusions

Five parts of Mendel's discoveries were an important divergence from the common theories at the time and were the prerequisite for the establishment of his rules.

1. Characters are unitary. That is, they are discrete (purple vs. white, tall vs. dwarf).
2. Genetic characteristics have alternate forms, each inherited from one of two parents. Today, we call these *alleles*.

3. One allele is dominant over the other. The phenotype reflects the dominant allele.
4. Gametes are created by random segregation. Heterozygotic individuals produce gametes with an equal frequency of the two alleles.
5. Different traits have independent assortment. In modern terms, genes are unlinked

5.2 Molecular genetics and inheritance

5.2.1 DNA, Gene, Chromosomes and Cell division

DNA stands for deoxyribonucleic acid and it is the molecule that holds the genetic information for a cell and an organism. DNA molecule contains a code that can be used by a cell to express certain genes. Specific sections of a DNA molecule provide the information to build specific proteins which can then be used by a cell to express the desired gene. DNA comes in the form of a long, linear molecule referred to as a strand. Each strand of DNA is bonded to a second strand of DNA to form a DNA double helix. In eukaryotic cells, DNA is found in the nucleus as a tightly coiled double helix. DNA molecules are replicated during cell division. When a cell divides, the two new cells contain all the same DNA that the original cell had. In sexual reproduction with two parents, half of the DNA of the offspring is provided by each of the parents. The genetic material of a child is made from 50% of their mother's DNA and 50% their father's DNA.

Structure of DNA and chromosome

Self-test

1. *What a chromosome really looks like?*
2. *How DNA is replicated?*
3. *How a DNA molecules stores information?*

Chromosome is a thread- like structure that is made up of DNA (deoxyribonucleic acid) and histone (a set of globular (3^0) proteins). While DNA is the molecule that stores genetic information whereas histone is the core of a chromosome around which chromosome's DNA wrapped is the loosely organized form of chromosome throughout the nucleus in loops when the cell is not dividing is called Chromatin. Individual chromosomes are not easily distinguished unless condensed. On the condensed organization of chromosome, genes are inactive while uncondensed or loose organization allows the genes to be active. As a cell prepares for cell division, the chromatin loops will have duplicated themselves and become compacted or “condensed” to form a chromosome that is visible under light microscope.

DNA-is made up two strands of polynucleotides joined together and twisted into a double helix and the strands are anti-parallel to each other. The basic unit of DNA strand is a nucleotide (monomers of DNA). There are four types of nucleotides:-

- Adenine (A) – containing nucleotide
- Guanine (G) – containing nucleotide
- Cytosine (C) - containing nucleotide
- Thymine (T) – containing nucleotide (in DNA, or Uracil (U) nucleotide in RNA)

All nucleotides have: a phosphate group, a pentose sugar (deoxyribose in DNA and ribose sugar in RNA) and one of four nitrogen bases- adenine, cytosine guanine and either thymine (DNA) or uracil (RNA).

Bonds between the sugar in one nucleotide and the phosphate group in the next hold the nucleotides together. The base does not take in this linking of the nucleotides in a strand. That is the reason why we say ‘sugar- phosphate’ backbone. The nucleotides in one strand are paired with the nucleotides in the other strand according to the base pairing- rule.

- ✓ Adenine – Thymine(uracil in RNA)
- ✓ Cytosine – Guanine

DNA is a very stable molecule at normal temperature. The hydrogen bonds hold the two strands together in position through the bases. The stability of the DNA molecule is important in ensuring the genetic code in the DNA molecule – does not become corrupted.

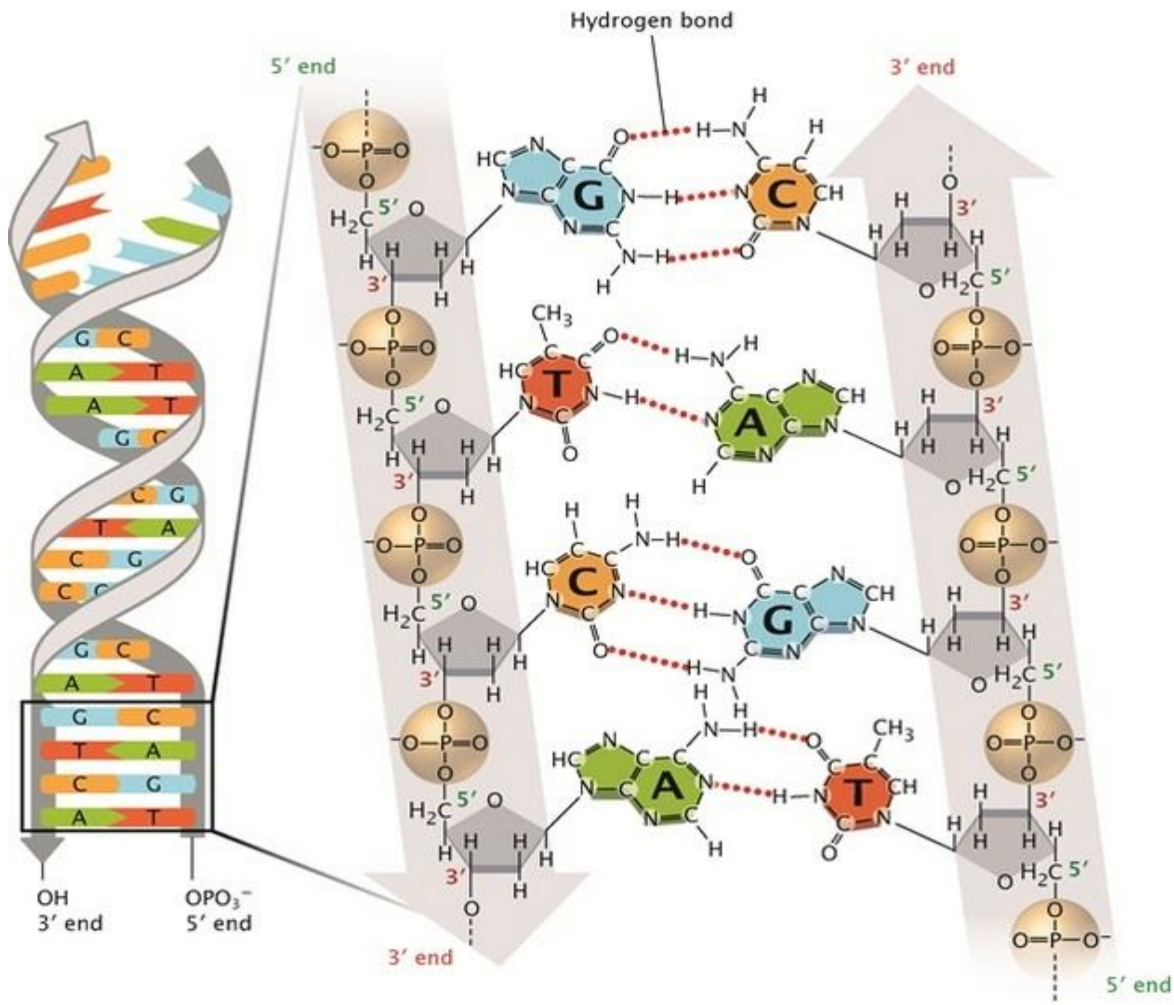


Fig:5.1. Structure of DNA

Activity

1. Recall structures and types of the four bases that make up nucleotide.

2. What types of bonds tie sugar to a phosphate group and the two Nitrogenous bases on each strands?

3. Why the DNA strands run anti-parallel and exist as a double helix?

DNA replication and cell division

Self test

1. What is the basis of all methods of reproduction and passing on genetic information through generations?

2. Recall the phases of eukaryotic cell division and describe briefly emphasizing on major events
3. What are the biological purposes of cell division?

The ability of DNA to make copy of itself (DNA-replication) is the basis for reproduction and inheritance. DNA molecule exists within chromosome (in the nucleus) and is surrounded by a 'soup' of free DNA nucleotides (which is to build new DNA molecules). DNA structure is double helix and must replicate semi-conservatively. Each formed new DNA molecule contains one strand from the original (old) DNA and one new strand DNA molecules. Both new DNA molecules formed are identical to each other and to the original molecule. Several Enzymes are involved in this process and the main stages are:

1. DNA helicase enzyme - break H-bonds to reveal two single strands and unwind (open) the helix DNA
2. DNA polymerase follows the helicase enzyme along each single-stranded region, which acts as a template for the synthesis of a new strand.
3. DNA polymerase assembles free DNA nucleotides into new strands alongside each of the template strands. The base sequence in each of these new strands is complementary to its template strand because of base- pairing rule, A-T, C-G.
4. Two-identical DNA molecules to each other and the original one is resulted. Each contains one strand from the original (old) and one newly synthesized.

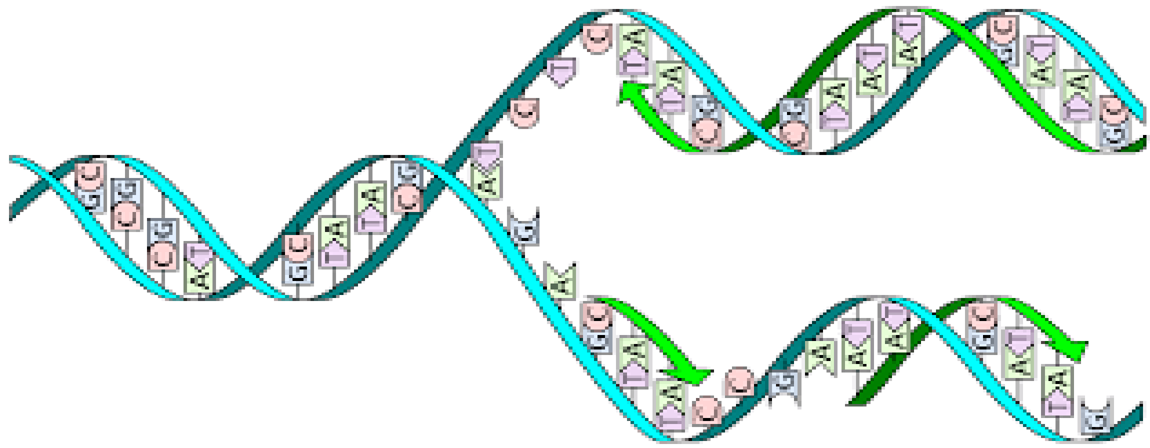


Fig: 5.2.

Cell division

Cell division is the process by which a parent cell divides into two or more daughter cells. Cell division usually occurs as part of a larger cell cycle. In eukaryotes, there are two distinct types of cell division: a vegetative division, whereby each daughter cell is genetically identical to the parent cell (mitosis), and a reproductive cell division, whereby the number of chromosomes in the daughter cells is reduced by half to produce haploid gametes (meiosis). Meiosis results in four haploid daughter cells by undergoing one round of DNA replication followed by two divisions. Homologous chromosomes are separated in the first division, and sister chromatids are separated in the second division. Both of these cell division cycles are used in the process of sexual reproduction at some point in their life cycle. Both are believed to be present in the last eukaryotic common ancestor.

Prokaryotes (bacteria) undergo a vegetative cell division known as binary fission, where their genetic material is segregated equally into two daughter cells. While binary fission may be the means of division by most prokaryotes, there are alternative manners of division, such as budding, that have been observed. All cell divisions, regardless of organism, are preceded by a single round of DNA replication.

For simple unicellular microorganisms such as amoeba, one cell division is equivalent to reproduction; an entire new organism is created. On a larger scale, mitotic cell division can create progeny from multicellular organisms, such as plants that grow from cuttings. Mitotic cell division enables sexually reproducing organisms to develop from the one-celled zygote, which itself was produced by meiotic cell division from gametes. After growth, cell division by mitosis allows for continual construction and repair of the organism. The human body experiences about 10 quadrillion cell divisions in a lifetime.

The primary concern of cell division is the maintenance of the original cell's genome. Before division can occur, the genomic information that is stored in chromosomes must be replicated, and the duplicated genome must be separated cleanly between cells. A great deal of cellular infrastructure is involved in keeping genomic information consistent between generations.

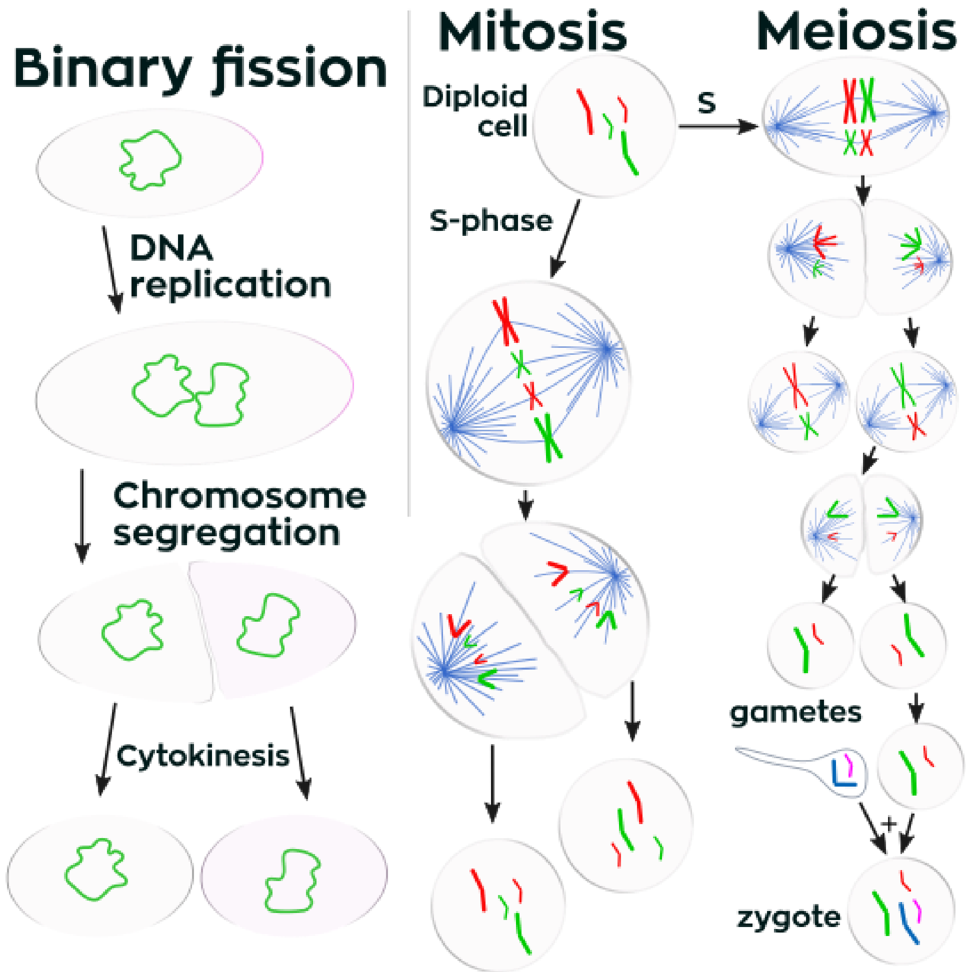


Fig: 5.3. Major types of cell division

Tips on cell division!!

Multicellular organisms replace worn-out cells through cell division. In some animals, however, cell division eventually halts. In humans this occurs, on average, after 52 divisions, known as the Hayflick limit. The cell is then referred to as senescent. With each division the cells telomeres, protective sequences of DNA on the end of a chromosome that prevent degradation of the chromosomal DNA, shorten. This shortening has been correlated to negative effects such as age related diseases and shortened lifespan in humans. Cancer cells, on the other hand, are not thought to degrade in this way, if at all. An enzyme complex called telomerase, present in large quantities in cancerous cells, rebuilds the telomeres through synthesis of telomeric DNA repeats, allowing division to continue indefinitely.

5.3 Protein synthesis

Self-test

1. What is genetic code?
2. How information stored on DNA is utilized?

Code for protein synthesis is specified by DNA and has to be sent to ribosome. DNA is a huge molecule and remains in nucleus to assemble amino acids in the correct sequence to form protein.

Events during protein synthesis

i. Transcription – DNA code for protein is rewritten in a molecule of messenger RNA (MRNA)
ii. MRNA travels from nucleus to ribosome
iii. Free amino acids are transported from cytoplasm to ribosome by transfer RNA (tRNA) molecules
iv. Ribosome read mRNA code and assembles amino acids presented by tRNA into a protein by a process = translation

Translation – is process in which mRNA code is converted into a sequence of amino acids

DNA $\xrightarrow{\text{transcription}}$ mRNA $\xrightarrow{\text{translation}}$ tRNA /RNA $\xrightarrow{\text{synthesis}}$ protein/polypeptide/

Genetic code

The genetic code is held in the DNA molecule. It is because of the nucleotides sequence in the DNA molecule made a gene that codes for protein to that each amino acid in the protein is coded for by a triplet /sequence of three bases/. Hence, a gene is a sequence of base triplets in the DNA molecule that carries a code for a protein.

1. Since there are 4 bases, there is 4^3 = 64 possible triplet codes /amino acids/ but only 20 amino acids are used to make all different proteins.

Activity
What is the purpose of the other 44 codes?

   None of them is spare or redundant.

2. Only one strands of a DNA molecule carries the code for proteins (It is called sense strand or coding stand) and the other strand is non-coding or antisense strand.
3. Most amino acids have more than one code, only methionine and tryptophan have one code.
   - Arginine has six codes

4. Three triplets (TAA, TAG, and TGA) do not code for amino acids and they are called stop codons. stop codes signify the end of the coding sequence
5. Degenerate code – the DNA code is non-overlapping codes i.e., each triplet is distinct from all other triplets.
6. The genetic code is also a universal codei.e. the triplet code TAT in the DNA code for amino acid tyrosine in human, redwood tree, bacterium or in any organism

   E.g. ACC – threonine, GGG-glycine

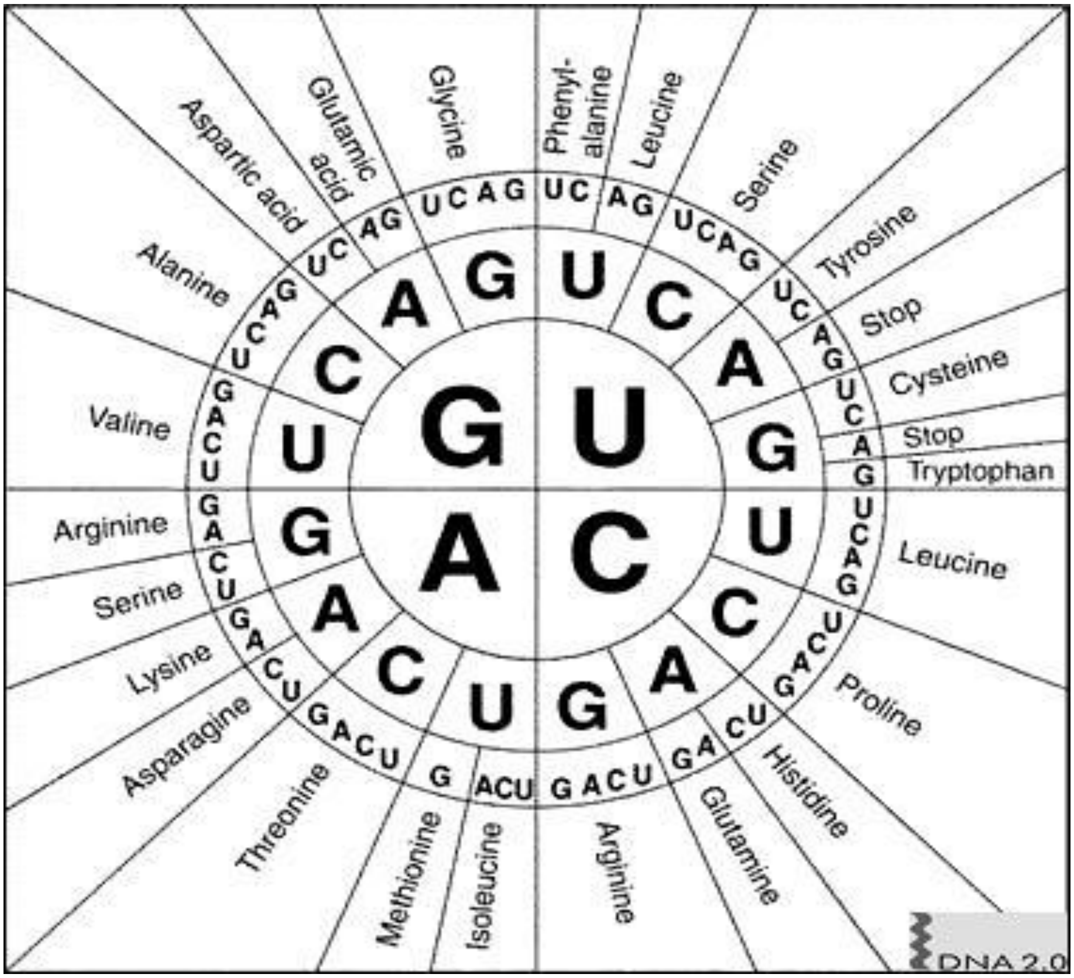


Fig:5.6. Genetic code

<u>N.B</u>. It is not just the base that matter but the sequence, e.g.ATT codes of different amino acid from TTA

The enzyme DNA-dependent RNA polymerase binds with a section of DNA next to the gene to be transcribed. Transcription factors activate the enzyme. The enzymes “unwind” and separate the strands of a DNA molecule. The polymerase assembles free RNA nucleotides on the complementary strand (antisense strand). mRNA (transcribed RNA) leaves the DNA; the strands of DNA rejoin & re-coil.

<u>N.B</u>. The mRNA molecule now contains the code for the protein that was held in the DNA of the genes

Activity

1. How does transcription take place in eukaryotic cells?

2. How does translation take place?

Translation of mRNA code into a protein depends on the interaction within a ribosome between mRNA and tRNA. All tRNA molecules have same basic structure. The "cloverleaf" configuration of the molecules has at one end a triplet of bases called anticodon. The anticodon is a triplet on tRNA. The other end of tRNA molecule has an attachment site for the aminoacid that is specified by the mRNA codon. Ribosomes are made from ribosomal RNA and proteins organized into large & small subunits. Within ribosome, there are three sites called A, P and E sites.

Events during translation of proteins

The first two codons of the mRNA enter the ribosome and tRNA molecules (with amino acid attached) that have complementary anticodons to the 1st two codons of the mRNA bind to those codons. A peptide bond forms between amino acid carried by two tRNA molecules and dipeptide is transferred to the tRNA in the A-site. The Ribosome moves along the mRNA by one codon bringing the 3rd codon into the ribosome. At the same time the free tRNA exits the ribosome from the E-site and tRNA with the dipeptide moves into the P-site. A tRNA with complementary anticodon binds with the third codon and brings its amino acid into position next to the 2nd. A peptide bond is formed between 2nd and 3rd amino acid. The whole process is repeated until a "stop" codon is in position and translation is stopped.

Note: - TGA, TAA and TAG – are stop codons.

N.B. The translation of the mRNA code into a protein molecule requires energy that comes from hydrolysis of GTP /guanoisne triphosphate/ not ATP

Self test

1. How is protein synthesis different in prokaryotic cells?

2. What are the fates of some of proteins-synthesized in our body?

Though it is similar to eukaryotes, there are some differences like: Prokaryotic cell have no nucleus. Prokaryotic mRNA does not need post-transcriptional process because it only contains exons (coding genes) not introns (non-coding genes). Transcription and translation are coupled - mRNA translated at one end of ribosome while it is start transcribing from DNA at other end.

Transamination: - is a process of amino group of an amino acid is removed and transferred to a keto acid, then it becomes a different amino acid/keto acid

E.g. pyruvic acid (keto acid) → alanine (amino acid) - by transamination.

Note. Not all amino acids are produced by transamination only those we obtain from our food. They are called essential amino acid.

Control of Gene expression

Self test

What controls gene expression? Switched on/off?

Genes are switched on by "transcription factors"- are proteins that bind to a regulatory sequence of DNA near to the gene they influence. They operate in the following way: The transcription factors bind to a promoter sequence of DNA near the gene to be activated. RNA polymerase binds to the DNA/ transcription factor complex. The RNA polymerase activated and moves away from the DNA along the gene. The RNA polymerase transcribes the antisense strand of the DNA and the gene is now being expressed.

Like transcription factors that promote gene expression, there are factors to repress (switched off) gene action. Short interfering RNA (siRNA)

- ✓ are unusual-very short
- ✓ only 21-23 nucleotides
- ✓ double stranded
- ✓ They don’t act on the gene itself, but interfere/silence the mRNA once it has been transcribed from DNA.

- ✓ Is post transcriptional interference

If mRNA is prevented from translating its Codons into amino acid then the protein for which the gene codes for cannot be built (silenced).

1.10.1.4 Mutations

Self-Test
1. What are mutations?
2. Is there a spontaneous change in the genetic material of an organism?
3. What causes mutation?
4. Are mutation useful, harmful or both? how?

Mutation is the alteration of the nucleotide sequence of the genome of an organism, virus, or extrachromosomal DNA.

- ☞ Mutation could occur spontaneously (accidentally) during duplication.
- ☞ They are rare events.
- ☞ Each cell contains $6x10^9$/billion/ base parts $\frac{1}{50\times10^6}$ occurrence
- ☞ Each new cell has an average 120 mutations. But
  - ✓ Most mutations detected & repaired
  - ✓ 95% of our DNA is non-coding, most mutation unlikely to affect coding gens.
- ☞ Rate of mutations can be increased by:-
  - ➢ Carcinogenic - chemical in tobacco smoke
  - ➢ High energy radiation- ultraviolet radiation, x- ray

There are many different ways that DNA can be changed, resulting in different types of mutiation as described below:

1. Point mutations- changes that involves a single base. There are several types of point mutations, some of these are:
   - ✓ Substitution- one base is replaced by other base
   - ✓ Addition-a base is missed out during DNA replication.
   - ✓ Deletions – an extra base is added.
2. Chromosomal Mutations- situation where part /segment/ of a chromosome sequence of DNA is disturbed/ a chromosome is missed/added. Types of chromosomal mutations:

- ❖ Euploidy/polyploidy/-is a condition where an organism/ a cell has one complete set of extra chromosomes/an exact multiple of a complete set.
  - ✓ Variation in number of chromosomes sets (one set of chromosome). E.g – Triploid ,Tetraploid
- ❖ Aneuploidy – is a condition where an organism/a cell lost from or added to one or more chromosomes to/the normal set of chromosome
  - ✓ 2 n+1 = trisomy/47 chromosomes, e.g. Down's syndrome
  - ✓ 2n-1 = monosomics – turner syndrome/45chr.
  - ✓ 2n+1+1 = double trisomy
  - ✓ 2n-2 – nullisomic, organisms that loss one homologous chromosome.

<u>Gidu syndrome</u> = mental retardation – caused by part of deletion of chromosome number 5 of man.

Consequence of gene-mutations

Mutations on body cell (non- sex cell) cannot be inherited but may result in one of the following:

- ➢ harmless
- ➢ damage the cell
- ➢ kill the cell
- ➢ Make cell cancerous- which might kill the person.

Mutations in different genes will obviously produce different effects but two types of gene are important in regulating cell division and preventing the formation of a tumor.

a. Proto-oncogenes-when proto-oncogenes mutate,they often become active oncogenes-which stimulate cell to divide in an uncontrolled manner.
b. Tumor-suppressor genes- recognize this uncontrolled cell division and act to suppress cell division.
   - ✓ If these genes mutate and become inactive, a tumor will form as uncontrolled cell division continues.
   - ✓ **Tumor**-is a mass of cells created when cell replication gets out of control and cause cancer.

Manipulation of DNA

Genetic engineering

Self test

1. What is genetic engineering?
2. What do you think of human cloning?

Genetic engineering is a process by which the genome of an organism is altered, usually by having extra (foreign) gene from different organisms, and the organism is termed genetically modified organism (GMO), transgenic organism or genetically engineered organism.

Genetic engineering is early done on Bactria, to produce useful products like:

- Insulin, antibiotics, washing enzyme
- Enzyme for food processing industry
- Human growth hormone
- Vaccines-Hepatitis B
- Bovine somatotrophin, high yield milk and muscle development in cattle.

Plants are also genetically modified:

- To absorb more CO_2 – global warming
- Disease (drought) resistant
- Improved yield
- To produce specific product e.g. golden rice produce beta-carotene (in vitamin 'A') prevent night blindness.

Moreover, animals are genetically modified for the following purposes

- high yield of protein, high growth rate
- Specific products eg. insulin,
- Detection of water pollution = glofish glow in the dark b/c they have had bioluminescent gene from jelly fish.
- Genetically modified salmon and Tilapia fish grow bigger and faster.

Some other potential applications of genetic engineering are:

- Disease could be prevented by detecting defected genes.
- To treat infectious diseases by implanting antiviral proteins (antibodies).

- To produce plants and animals that have high growth rate and reduced susceptibility to disease – reduce use of fertilizers and pesticides.
- Animals and plants can be 'tailor made' to show desirable characteristics

5.1.2 ABO blood groups and Rh Factors

Self-test

1. What is the basis of blood grouping?

2. What is the importance of blood group in blood transfusion, pregnancy, forensic science and paternity check?

3. Why AB and O blood groups are said as the *universal recipient and donor respectively?*

Early experiments with human blood transfusion often resulted in the death of the patient for unknown reasons. In 1901, it was discovered that there were three blood types, A, B, and O, and that mixing blood from different types caused an immune response that resulted in clumping. Type AB is rare and was discovered later.

ABO Blood Type: An individual's red blood cells will contain proteins of type A, or B, or both, or neither. The body produces antibodies that will attack any foreign type. Alleles of types $\mathbf{I_A}$ and $\mathbf{I_B}$ are dominant over type **i**.

Table 5.1 Types of blood

Genotype	**Blood Type**	Antigens	**Antibodies**	**Donate To**	**Receive From**
i i	Type O	None	Anti-A and Anti-B	A, B, AB, O	O
I_A I_A	Type A	A	Anti-B	A, AB	A, O
I_A i	Type A	A	Anti-B	A, AB	A, O
I_B I_B	Type B	B	Anti-A	B, AB	B, O
I_B i	Type B	B	Anti-A	B, AB	B, O
I_A I_B	Type AB	A and B	None	AB	A, B, AB, O

Rh Factor (D antigen): The Rh factor, the second most important blood group system after the ABO blood group system, was first discovered in Rhesus monkeys. The Rh factor is inherited independently from the ABO blood type. Genotypes for the Rh factor are +/+, +/-, and -/-. People who are +/+ or +/- possess the Rh(D) antigen and test as Rh positive. People who are -/- do not posess the Rh(D) antigen and test as Rh negative.

Genotype	Phenotype	Blood Proteins	Blood Antibodies	Donate To	Receive From
+/+	Rh+	Rh(D) proteins	None	Rh+	Rh+ or Rh-
+/-	Rh+	Rh(D) proteins	None	Rh+	Rh+ or Rh-
-/-	Rh-	None	Anti-Rh(D)	Rh+ or Rh-	Rh-

Rh Sensitization: One interesting medical scenario involves an Rh negative mother who carries an Rh positive baby. The baby of an Rh positive father and an Rh negative mother can be +/- or -/-.) If the baby is +/-, the first pregnancy causes Rh sensitization in the mother, because she is exposed to foreign proteins and builds up antibodies against them. Future pregnancies can be increasingly difficult, as the mother's antibodies attack the baby.

Activities

Table 1: The following tables give information on human blood types needed in problems below. Alleles of types I_A and I_B are dominant over type i.

Genotype	Blood Type	Blood Proteins	Blood Antibodies
i i	Type O	None	Anti-A and Anti-B
I_A I_A	Type A	A	Anti-B
I_A i	Type A	A	Anti-B
I_B I_B	Type B	B	Anti-A
I_B i	Type B	B	Anti-A
I_A I_B	Type AB	A and B	None

Genotype	Phenotype	Blood Proteins	Blood Antibodies
+/+	Rh+	Rh(D)	None
+/-	Rh+	Rh(D)	None
-/-	Rh-	None	Anti-Rh(D)

1. A patient is rushed to the emergency room and has suffered severe blood loss. Type AB blood is in short supply, but the nurse says "Don't worry, he's type AB positive. We can give him any kind of blood." Explain. (Why is type AB called the universal recipient?)

2. On the battlefield, a medic is treating a soldier who has lost a great deal of blood. They are out of blood typing supplies so the medic, who is Type O negative, simply donates his own blood to the patient. Why could this work? (Why is Type O called the universal donor?)

3. There is a practical joker in the maternity ward who removed all the baby id bracelets. There are three babies that cannot be easily distinguished and the parents want to be sure they get the right ones back so the doctors do a blood test. A particular mom is homozygous type A and the dad is type O. The babies have blood types AB, A, and O. Show your work below and indicate which baby must be theirs.

		MOM	
DAD		$\mathbf{I_A}$	$\mathbf{I_A}$
	i	I_Ai	I_Ai
	i	I_Ai	I_Ai

4. The police have rounded up the usual suspects in the latest rash of bookstore robberies. The thief got a nasty paper cut at the scene of the crime. The suspects are of blood types O, A, B and AB. The blood at the crime scene contained i alleles. Which suspect therefore **cannot** have been involved? Explain.

Suspect 1	Blood Type O	Possible Genotype(s):	ii
Suspect 2	Blood Type A	Possible Genotype(s):	I_AI_A or I_Ai
Suspect 3	Blood Type B	Possible Genotype(s):	I_BI_B or I_Bi
Suspect 4	Blood Type AB	Possible Genotype(s):	I_AI_B

5. In a paternity case, a single mother claimed that a certain man was the father of her baby. The man denied it, claiming that her current boyfriend was the father. The court ordered a

blood test (much cheaper than DNA testing) to see if he could be ruled out as the father. The mother was Type O and the baby was Type O. The man was Type AB. Is it **possible** that he was the father? Why or why not?

6. Why is it that a blood type test can only **disprove** but never prove paternity? Why are DNA tests used to "prove" paternity instead?

7. (True Story) In Denmark, a husband and wife who had been unsuccessfully trying to have a baby went to a fertility clinic. Sperm and eggs were collected from father and mother, and combined in a petri dish, creating several "test-tube babies". These babies were implanted in the mother and 9 months later she delivered twins, one with light skin and one with dark skin. Because this seemed strange, a DNA test was conducted and it was found that both children were related to the mother, but only the light skinned child was related to the father. How can this be explained?

8. Rh factors are proteins that were first discovered in the blood of Rhesus Monkeys, but humans have them too. If you are Rh positive, it means that there are Rh type proteins in your blood. If you are Rh negative, there are no Rh type proteins in your blood. Positive is dominant over negative, so heterozygous individuals are Rh positive. Problems can arise when an Rh negative mother has a child who is Rh positive. Why does the mother's body attack her own baby in this situation? Why does the situation get worse for the second pregnancy?

9. The father of two children is type O+, and the mother is type A+. The children are O- and A+. Given this information, what can you say about the genotypes of father and mother?

5.4 Introduction to Evolution

Self-test
1. What are the main creationist views on the origin of life on Earth?
2. Explain how Francisco Redi and Louis Pasteur disproved spontaneous generation theory.
3. How evidences of evolutionist theory support the process of evolution?

Evolution is the gradual change of organisms on the earth over long periods, with new forms replacing old ones. As evolution has progressed new species are arising, the biodiversity of the planet increasing, larger and more complex organisms replaced the smaller and some species has get extinct.

5.4.1 Theories on the origin of life on Earth

Evolution can also be the change in genetic composition of a population over successive generations which may be caused by meiosis, hybridization, natural selection or mutation. This leads to a sequence of events by which the population diverges from other populations of the same species and may lead to the origin of a new species. Theories about the origin of life on Earth. The theory of evolution describes how the various forms of life on earth (including humans) emerged and developed. There are five main theories of the origin of life on Earth:

- ✓ special creationism
- ✓ spontaneous generation
- ✓ eternity of life
- ✓ cosmozoan theory
- ✓ biochemical origin

a) Special creationism

Special creation theory states that the different forms of life on earth were created by a Supreme Being/ God/ at once with six days. Special creation is always linked to religion and mainly focused on spiritual matters that cannot be seen, touched or measured effectively. There are two views on the origin of life:

Types of creationism theory

Gap creation – discusses a large gap between the formation of the earth and the creation of all the animals and plants. The gap could be billions or millions of year.

Progressive creation – accepts the Big Bangs as the origin of the universe. It accepts the fossil record of a series of creation for all of the organisms but it does not accept these as part of a continuing process (each is seen as unique creation).

Evolutionary creationism (Theistic evolution) – This view of evolution maintains that God 'invented' evolution and takes some form of an active part in the ongoing process of evolution.

Intelligent design – a theory states that life developed (formed) due to a combination of natural forces and the intervention of a supernatural being.

b) Spontaneous generation theory

Suggests that life can evolve 'spontaneously' from non-living objects. E.g. people believed that rotting meat turned into flies.

c) Eternity of life

The theory of eternity of life states that the universe has always existed and that there has always been life in the universe. There is no beginning and no end to life on earth and so life is neither created nor generated from non-living matters

d) Cosmozoan Theory

States that life on the earth originally came from elsewhere in the universe (possibly from another planet). E.g. Meteorites brought bacterial spores, germs to the earth. This theory did not gain any significant support because it lacks evidence and it is strongly linked to the 'eternity of life' theory of the origin life.

e) Biochemical theory

It suggests that life on earth originated as a result of a number of biochemical reactions producing organic molecules, which combined (associated) to form cells. This theory is also called abiogenesis; states life originates from chemical inanimate (abiotic substances). The two scientists (biologists) who developed the theory of abiogenesis (origin of life from chemicals) were:- Aleksander Oparin (1924) and John Haldane (1929). They both suggested:

- The primitive atmosphere of the earth was a reducing atmosphere – no free oxygen (no oxygen gas).

- There was an appropriate supply of energy, such as lightening or ultraviolet light (Uv – rays).
- This would provide the energy for reactions that would synthesize a wide range of organic compounds (amino acids, sugars and fatty acids).

Oparin suggested that the atmosphere of the primitive earth contained NH_3, H_2, water vapour (H_2O (g)) and CH_4. He suggested that at high temperature (above boiling point), these gases could have undergone a series of chemical reactions and might have formed colloidal aggregates or coacervates (collections of droplets that composed of molecules of different types). Oparin considered that these coacervates were able to absorb and assimilate organic compounds (amino acids, DNA and others) and leading to the first true cells.

J. Haldane – proposed that the chemical reactions of these gases were occurred in the primitive sea by solar energy and the sea became a 'hot dilute soup' of organic monomers and small polymers.

In 1953, Stanley Miller tested the biochemical theory. He applied electrical sparks repeatedly through a mixture of gases (NH_3, water, H_2 and CH_4) that were represent the primitive atmosphere of the earth (no oxygen) connected a flask of heated water.

Miller leaving the equipment for longer periods of time, a larger variety and more complex organic molecules were formed including:

- amino acids - to form proteins
- pentose sugar - to form nucleic acids
- hexose sugar - need for respiration and to form starch and cellulose.
- Hydrogen cyanide (HCN)- starting point for synthesizes of nitrogen containing bases in nucleotides.

This experiment gave strong evidence to support the Oparin-Haldane hypothesis.

Origin of Autotrophy: The first life (cell) appeared on earth – about 4 billion years ago and they were:- anaerobes, heterotrophs and prokaryotes. They would have fed on organic chemicals (soup) which formed spontaneously in the waters of the earth. The three consecutive lines of evolution of organisms on earth leading to:

- Archaebacteria - are first appeared organisms. They are prokaryotes including thermophilic (high temp. loving), sulphobacteria, methanobacteria and halophilic (salt loving) bacteria.

They can survive under harsh (extreme) environment.

- Eubacteria – are true (ordinary) bacteria, ordinary bacteria and cyanobacteria (blue – green algae)
- Prokaryotes – evolved into protista, fungi, plants, animals (nearly all are aerobes).

Later (3.5 billion years ago) – the first autotrophs (photosynthetic organisms) like cyanobacteria (blue-green algae) came in existence. With the evolution of chlorophyll molecules, oxygen (O_2) was released as a by-product of photosynthesis and this changes the earth's atmosphere from the reducing to an atmosphere containing oxygen. The fossil record shows that cyanobacteria had been producing oxygen by photosynthesis from about 305 million years ago but the levels of oxygen in atmosphere did not rise for almost 1 billion years ago. Because oxygen was absorbed by the vast amount iron in the earth it rusted.

5.4.2 Theories of Evolution

There have been many theories of evolution that have explained:- how does evolution happen? And what drives the population to become a new species?

A. Lamarck Theory of evolution

In the 19th century (1809), Lamarck published a paper entitled Philosophic 'Zoologique' in which he described the two-part mechanism by which change was gradually introduced into the species and passed down through the generations. This theory is also called 'theory of transformation' or Lamarckism. The two parts of Lamarck theory are:

- Use and disuse
- Inheritance acquired traits

Use and disuse – Lamarck suggested that a structure or process in organism that can be used continuous will become enlarged or more developed but any structure that is not. Example, According Lamarck, giraffe had short neck but they stretched their neck to reach high branches, developed an elongated neck use theory. The wings of penguins would have become smaller than those of other birds because penguins do not use their wings to fly disuse theory. Inheritance of Acquired traits – Lamarck believed that traits changed (acquired during an organism's lifetime could be passed on to its offsprings. Example: - Giraffes that had acquired long necks would have offspring with long necks.

Note: - Nowadays, Lamarck's theories are not accepted because the environmental changes that were believed by Lamarck have brought about the changes in the phenotypes (Physical appearance) of the organisms have no effect on their gametes and hence their heredity.

B. Charles Darwin and Natural Selection

In 1858, both Charles Darwin and Alfred Wallace jointly published a scientific paper that proposed species were modified by natural selection. Darwin visited five of the Galapagos Islands, made drawings, and collected species. In particular, Darwin studied the finches found on the different islands and noted there were many similarities between them but have some obvious differences. Darwin concluded that an "ancestral finch" had colonized the Islands from mainland and been able to adapt to the different conditions on the islands and evolve into different species. E.g. He suggested that some finches had evolved into insect eaters (pointed peak), other in to seedeaters (crushing peak). Darwin summarized his observations in two main ideas:

- all species tend to produce more offsprings than can possibly survive (Fecundity)
- There is a variation among the offsprings.

From these observation Darwin deduced (concluded) that:

- There will be a "struggle for existence" between members of a species because they are over – reproduced and resources are limited.

- Some members of a species will be better adapted than others to the environment because there is a variation in the offspring.

Darwin proposed: - Those members of a species, which are best adapted to their environment, will survive and reproduce in greater number than other less adapted (died out).

C. Neo – Darwinism Theory

Charles Darwin knew very little about genetics and did not propose how a variation in the population was passed to the next generation. Now day's genes and gene action are the driving force of evolution in the theory of Natural selection. A Gene pool is all the alleles in the population. It might be evolve a population into a new species. Suppose an allele determines a feature that gives an organism an advantage in its environment. The following will happen

- Those individuals with the advantageous allele of a gene will survive to reproduce in greater number than other types
- Advantageous alleles pass to their offsprings in greater numbers than other genes (alleles).
- The frequency of the advantageous allele will be higher in the next generation of a population.

Mutations are important in introducing variation into population. Any mutation could produce an allele which:

- Increase in frequency if they are beneficial in their effect, may increase slowly, stable or decrease if they are neutral and decrease and could disappear if they are harmful (disadvantages) in their effects.

Neo-Darwinism is a modification of Darwin's original theory that takes into account: - genetics and ethology(behavioral patterns can also be advantageous or not). E.g. Young geese 'imprint' upon the first moving object after they are hatched.

Unit 6

Infectious diseases and Immunity

Learning Objectives: upon successful completion of this unit, you should be able to:

- ✓ *Explain the relationship between infections and immunity*
- ✓ *Identify different types of infectious diseases and their modes of transmission*
- ✓ *Explain different mechanisms of innate and adaptive immunity*
- ✓ *Explain principle of infection*
- ✓ *Discuss classification of disease by occurrence and duration*
- ✓ *Explain pathogen city*
- ✓ *Identify the causative agents of diseases*
- ✓ *Explain transmission modes of diseases*
- ✓ *Understand the host defense mechanism against diseases*
- ✓ *Differentiate innate and adaptive immunities*
- ✓ *Discuss interactions of innate and adaptive immunities in protecting the body against infections*
- ✓ *Analyze the adverse immune reactions and the major damaging effects of the immune system*
- ✓ *Understand immune reactivity against tumors*

Self-test

1. What are the important steps to cause infection?

2. What make infectious diseases different from other types of diseases?

Infectious diseases are diseases caused by living organisms called infectious agents like bacteria, viruses, fungi, protozoa, and helminthes and prions, It occurs as the result of interactions between pathogenic (disease-producing) microorganisms and the host. All infectious diseases begin at some surface of the host, whether it is the external surfaces such as the skin and conjunctiva or internal surfaces such as the mucous membranes of the respiratory tract, intestine, or urogenital tract.

In order to cause infectious disease a pathogen must accomplish the following steps:-

1. It must enter the host,
2. It must metabolize and multiply on or in the host tissue.
3. It must resist host defenses
4. It must damage the host.

In order to cause disease, pathogens must be able to enter the host body, adhere to specific host cells, invade and colonize host tissues, and inflict damage on those tissues. Entrance to the host typically occurs through different entry route such as the mouth, eyes, or genital openings, or through wounds that breach the skin barrier to pathogens. Although some pathogens can grow at the initial entry site, most must invade areas of the body where they are not typically found. They do this by attaching to specific host cells. Some pathogens then multiply between host cells or within body fluids, while others such as viruses and some bacterial species enter the host cells and grow there. Although the growth of pathogens may be enough to cause tissue damage in some cases, damage is usually due to the production of toxins or destructive enzymes by the pathogen.

6.1 Principles of infectious diseases

Infection and disease

The terms "infection" and "disease" are not synonymous. An **infection** results when a infectious agent (pathogen) enters and begins growing within a host.

Disease occurs when the cells in host body are damaged, tissue function is impaired as a result of the **infection** and signs and symptoms of an illness appear.

Sign, symptom and syndrome

- **Symptom**: A change in body function that is felt by a patient as a result of disease
- **Sign**: A change in a body that can be measured or observed as a result of disease.

Signs *(objective)* ***Symptoms*** *(subjective)*

- **Syndrome**: A specific group of signs and symptoms that accompany a disease

Classifying infectious diseases

- **Communicable disease**: A disease that is spread from one host to another

- **Contagious disease**: A disease that is easily spread from one host to another
- **Non-communicable disease**: A disease that is not transmitted from one host to another

Classifying infectious diseases by occurrence of diseases

- **Incidence**: fraction of a population that contracts a disease during a specific time
- **Prevalence**: fraction of a population having a specific disease at a given time
- **Sporadic disease**: disease that occurs occasionally in a population
- **Endemic disease**: disease constantly present in a population
- **Epidemic disease**: disease acquired by many hosts in a given area in a short time
- **Pandemic disease**: worldwide epidemic

Severity or duration of infectious disease

Scope of infectious disease can be defined as:-

- **Acute**: disease develops rapidly
- **Chronic**: disease develops slowly
- **Subacute**: symptoms appear between acute and chronic
- **Latent**: disease with a period of no symptoms when the causative agent is inactive

Extent of host involvement:

An Infection of Infectious disease can be

- **Local infection**: Pathogens are limited to a small area of the body
  - abscesses
- **Systemic infection**: an infection throughout the body by blood and/or lymph
  - **Bacteremia**: bacteria in the blood
  - **Sepsis**: toxic inflammatory condition arising from the spread of microbes, especially bacteria or their toxins, from a focus of infection
  - **Septicemia**: growth of bacteria in the blood
  - **Toxemia**: toxins in the blood

- **Viremia**: viruses in the blood
- **Focal infection**: systemic infection that began as a local infection
    - local tooth infection can moves via blood or lymph to set up a new infection at another site - rheumatoid arthritis
- **Primary:** acute infection causing initial illness
- **Secondary**: occurs after host is weakened from primary infection
- **Subclinical** (inapparent): no noticeable signs and symptoms

Disease development and stages

- **Incubation period:** time interval between initial infection and first appearance of signs and symptoms.
- **Prodromal period:** characterized by appearance of first mild signs and symptoms.
- **Period of illness**: disease at its height: all disease signs and symptoms apparent.
- **Period of decline:** signs and symptoms subside.

- **Period of convalescence:** body returns to prediseased state, health is restored.

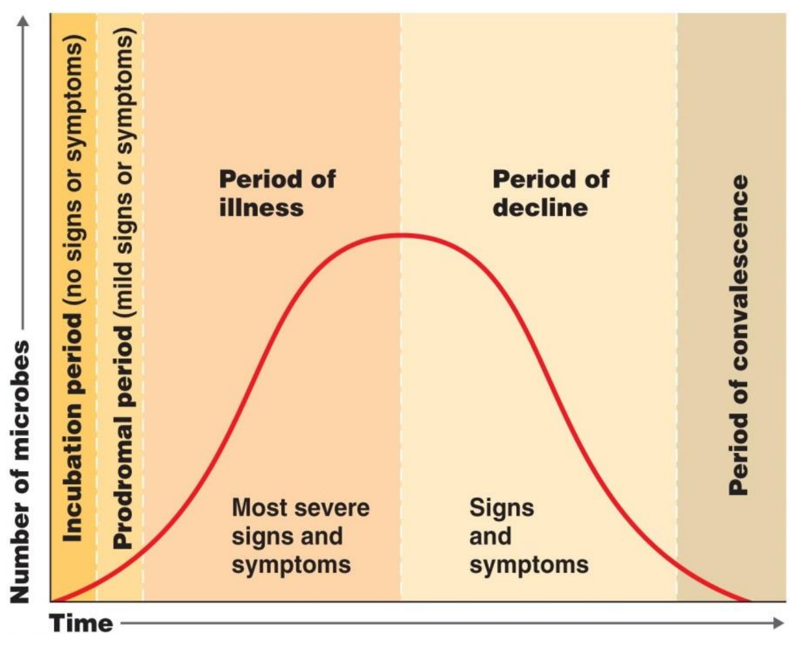


Fig: 6.1 development and stages of a disease

6.1.1 Pathogenicity

Self-test
What are opportunistic pathogens?

We contact numerous microorganisms daily when we breathe in, ingest with food and drink, and pick up on skin. Most microbes are harmless and many are beneficial. Vast majority generate no ill effects and relatively few are pathogens that cause damage. These microorganisms are classified based on their pathogenicity:-

Primary pathogen is microbe or virus that causes disease in otherwise healthy individual. Diseases such as plague, malaria, measles, influenza, diphtheria, tetanus, tuberculosis, etc. These pathogenic organisms are called virulent because of their virulence factor. Virulence refers to a degree of pathogenicity, which is caused by virulence factors are traits that allow microorganism to cause disease.

Opportunistic pathogen (opportunist) causes disease only when body's innate or adaptive defenses are compromised or when introduced into unusual location. It can be members of normal microbiota or common in environment (e.g., *Pseudomonas*).

Normal microbiota (normal flora) are organisms that routinely reside on body's surfaces and the relationship is delicate balance and some can cause disease if opportunity arise. This is due to the fact that weaknesses or defects in innate or adaptive defenses can leave individuals vulnerable to invasion.

- These individuals are said to be immune-compromised
- Factors include malnutrition, cancer, AIDS or other disease, surgery, wounds, genetic defects, alcohol or drug abuse, and immunosuppressive therapy following procedures such as organ transplants.

6.1.9. The spread of infection

- **Human reservoirs of infection -** people who have a disease or are carriers of pathogenic microorganisms.
    - Sick people = actively ill
    - Carriers = one who harbors disease organisms in their body without manifest symptoms (healthy).
    - Latent infection carriers = contagious during incubation period or convalescent period.

- **Zoonoses** - are diseases that affect wild and domestic animals and can be transmitted to humans.
    - Direct contact with animal or its waste
    - Eating animals
    - Blood sucking arthropods
- **Nonliving reservoirs** - soil, water, and food can be reservoirs of infection.
        - Presence of microorganisms is often due to contamination by feces or urine.

Activity: -
1. Discuss the differences between:-
- *Infection and diseases*
- *Sign and Symptom*
- *Incidence and prevalence*
- *Endemic and epidemic*
- *Acute and Chronic*
- *Primary and secondary infection*

6.2 Types of infectious disease and their causative agent

Bacteria, viruses, fungi, protozoa, parasites, and prions are different types of pathogen. They vary in their size, shape, function, genetic content, and how they act on the body. For example, viruses are smaller than bacteria, and they can enter a host and take over cells. However, bacteria can survive without a host.

The common pathogens known as causative agents for different types of infectious diseases are:-

6.2.1 Bacteria

Self-test

List at least five infectious diseases caused by bacteria

Bacteria are unicellular prokaryotic organisms; they have circular genomes, double-stranded DNA that is associated with much less protein than eukaryotic genomes. Most bacteria reproduce by growing and dividing into two cells in a process known as binary fission.

Despite their commonalities that group them together in the Kingdom Monera, there are a variety of morphologies among them, but three of the most common are bacillus (rod-shaped), coccus (spherical), or spirillum (helical rods). The energy sources for bacteria also vary. Some bacteria are photosynthetic and obtain their energy directly from the sun. Others oxidize inorganic compounds to supply their energy needs. Still other bacteria generate energy by breaking down organic compounds such as amino acids and sugars in a respiratory process. Some bacteria require oxygen (aerobes), while others are unable to tolerate it (anaerobes). Some bacteria can grow either with or without oxygen (facultative anaerobes).

Bacteria are frequently divided into two broad classes based on their cell wall structures, which influences their Gram stain reaction. Gram-negative bacteria appear pink after the staining procedure. Familiar pathogenic gram-negative organisms are *Salmonella typhi*, which causes typhoid fever, and *Yersinia pestis*, which causes plague. Gram-positive bacteria appear purple after the Gram staining procedure. Examples of pathogenic gram-positive bacteria are *Staphylococcus aureus*, which causes skin, respiratory, and wound infections, and *Clostridium tetani*, which produces a toxin that can be lethal for humans.

There are trillions of strains of bacteria, and few of these cause diseases in humans. Some of them live inside the human body without causing harm, for example in the gut or airways. Some bacteria attack other bacteria and prevent them from causing sickness.

However, some bacterial diseases are deadly which include: cholera, diphtheria, dysentery, bubonic plague, pneumonia, tuberculosis, typhoid, typhus and etc.

Some examples of bacterial infections are: bacterial meningitis, otitis media, pneumonia, tuberculosis, upper respiratory tract infection, gastritis, food poisoning, eye infections, sinusitis, urinary tract infections, skin infections and sexually transmitted diseases. Bacterial infections can be treated with antibiotics, but some strains become resistant and can survive the treatment.

6.2.2 Viruses

Viruses can infect all organisms, from plants and animals to fungi and bacteria. Viruses, however, are not organisms themselves because, apart from a host cell, they have no metabolism and cannot reproduce. A virus particle is composed of a viral genome of nucleic acid that is surrounded by a protein coat called a capsid. In addition, many viruses that infect animals are surrounded by an outer lipid envelope, which they acquire from the host cell membrane as they leave the cell. Unlike organisms, in which the genetic material is always double-stranded DNA, viral genomes may be double- or single-stranded DNA (a DNA virus), or double- or single-stranded RNA (an RNA virus).

In the general process of infection and replication by a DNA virus, a viral particle first attaches to a specific host cell via protein receptors on its outer envelope, or capsid. The viral genome is then inserted into the host cell, where it uses host cell enzymes to replicate its DNA, transcribe the DNA to make messenger RNA, and translate the messenger RNA into viral proteins. The replicated DNA and viral proteins are then assembled into complete viral particles, and the new viruses are released from the host cell. In some cases, virus-derived enzymes destroy the host cell membranes, killing the cell and releasing the new virus particles. In other cases, new virus particles exit the cell by a budding process, weakening but not destroying the cell.

In the case of some RNA viruses, the genetic material can be used directly as messenger RNA to produce viral proteins, including a special viral RNA polymerase that copies the RNA template to produce the genetic material for new viral particles. Other RNA viruses, called retroviruses, use a unique enzyme called reverse transcriptase to copy the RNA genome into DNA. This DNA then integrates itself into the host cell genome. These viruses frequently exhibit long latent periods in which their genomes are faithfully copied and distributed to progeny cells each time the cell divides. The human immunodeficiency virus (HIV), which causes AIDS, is a familiar example of a retrovirus.

Viruses cause disease by disrupting normal cell function. They do this in a variety of ways. Some viruses make repressor proteins that stop the synthesis of the host cell's proteins, RNA, and DNA. Viral activity may weaken cell membranes and lysosomal membranes, leading to cell autolysis. Some viral proteins are toxic to cells, and the body's immune defenses also may kill virus-infected cells.

Viruses are classified using a variety of criteria, including shape, size, and type of genome. Among the DNA viruses are the herpes viruses that cause chicken pox, cold sores, and painful genital lesions, and the poxvirus that causes smallpox. Significant RNA viruses that cause human disease include rhinoviruses that cause most common colds; myxoviruses and paramyxoviruses that cause influenza, measles, and mumps; rotaviruses that cause gastroenteritis; and the retroviruses that cause AIDS and several types of cancer.

Viruses invade a host and attach themselves to a cell. As they enter the cell, they release genetic material. The genetic material forces the cell to replicate, and the virus multiplies. When the cell dies, it releases new viruses, and these go on to infect new cells. Not all viruses destroy their host cell. Some of them change the function of the cell. In this way, viruses such as human papillomavirus (HPV) or Epstein-Barr virus (EBV) can lead to cancer by forcing cells to replicate in an uncontrolled way.

.A virus may remain dormant for a period before multiplying again. The person with the virus can appear to have recovered but may get sick again when the virus reactivates. Antiviral medications help in some cases. They can either prevent the virus from reproducing or boost the host's immune system.

Antibiotics are not effective against viruses. Using antibiotics against a virus will not stop the virus, and it increases the risk of antibiotic resistance. Most treatment aims to relieve symptoms while the immune system combats the virus without assistance from medicine.

6.2.3 Fungi

Self-test

1. What are the important characteristics of fungi which make them different from virus and bacteria?

2. Why most of fungal treatments are topical?

Fungi are eukaryotic, heterotrophic organisms that have rigid cellulose- or chitin-based cell walls and reproduce primarily by forming spores. Most fungi are multicellular, although some, such as yeasts, are unicellular. Together with bacteria, fungi fulfill the indispensable role of decomposers in the environment. Many fungal infections will appear in the upper layers of the skin, and some progress to the deeper layers. Inhaled fungal spores can lead to systemic fungal infections, such as thrush, or candidiasis. Systemic diseases affect the whole body.

Those with a higher risk of developing a fungal infection include people who:

- use strong antibiotics for a long time
- have a weakened immune system, due, for example, to HIV or AIDS, diabetes, chemotherapy treatment, and those who have undergone a transplant, as they take medications to prevent their body from rejecting the new organ

Many fungi infect plants and animals. Examples of diseases caused by fungi are ringworm and histoplasmosis (a mild to severe lung infection transmitted by bat or bird droppings). Yeasts of the *Candida* genus are opportunistic pathogens that may cause diseases such as thrush (a throat infection) among people who are immunocompromised or undergoing antibiotic therapy.

6.2.3 Protozoa

Self test

What are the five common plasmodium species?

Protozoa are unicellular, heterotrophic eukaryotes that include the familiar amoeba and paramecium. Because protozoa do not have cell walls, they are capable of a variety of rapid and flexible movements. Protozoa can be acquired through contaminated food or water or by the bite of an infected arthropod such as a mosquito. Diarrheal disease can be caused by two common protozoan parasites, *Giardia lamblia* and *Cryptosporidium parvum*. Malaria, a tropical illness that causes 300 million to 500 million cases of disease annually, is caused by different species of the protozoan *Plasmodium*.

6.2.4 Helminths

Helminths are simple, invertebrate animals, some of which are infectious parasites. They are multicellular and have differentiated tissues. Because they are animals, their physiology is similar in some ways to ours. This makes parasitic helminth infections difficult to treat because drugs that kill helminths are frequently very toxic to human cells.

Many helminths have complex reproductive cycles that include multiple stages, many or all of which require a host. The common helminthes are Ascaries, tape worm, hook worm *Schistosoma* etc.

6.2.6. Prions

Self-test

How do prions replicate in the host body?

A prion is a protein that contains no genetic material. It is normally harmless, but if it folds into an abnormal shape, it can become a rogue agent and affect the structure of the brain or other parts of the nervous system. Prions do not replicate or feed on the host but trigger abnormal behavior in the body's cells and proteins.

The known prion diseases include Creutzfeldt-Jakob disease (in humans), scrapie (in sheep), and bovine spongiform encephalopathy ("mad cow disease" in cattle); all known prion diseases frequently result in brain tissue that is riddled with holes. While some prion diseases are inherited, others are apparently due to infection by eating infected tissue or inadvertently through medical procedures such as tissue transplants.

Activities

1. What is the main difference between bacteria and virus?

2. Why antibiotics are not effective to cure virus infections?

3. Why viral drug discovery remains difficult?

4. List two examples of aerobic and anaerobic bacteria.

5. What makes gram positive bacteria different from gram negative bacteria?

6. Explain abut replication of DNA virus.

7. Discuss on the life cycle of plasmodium in human host and vector.

8. Which helminthes needs vector animal in its transmission route?

6.3 Modes of transmission

Self-test

1. *Why do infectious agents transmit from infected host to healthy host?*
2. *What is the difference between horizontal and vertical mode of transmission?*

Infectious agents may be transmitted through either direct or indirect contact. Direct contact occurs when an individual is infected by contact with the reservoir, for example, by touching an infected person, ingesting infected meat, or being bitten by an infected animal or insect. Transmission by direct contact also includes inhaling the infectious agent in droplets emitted by sneezing or coughing and contracting the infectious agent through intimate sexual contact. Some diseases that are transmitted primarily by direct contact with the reservoir include ringworm, AIDS, trichinosis, influenza, rabies, and malaria.

Indirect contact occurs when a pathogen can withstand the environment outside its host for a long period of time before infecting another individual. Inanimate objects that are contaminated by direct contact with the reservoir (for example, a tissue used to wipe the nose of an individual who has a cold or a toy that has been handled by a sick child) may be the indirect contact for a susceptible individual. Ingesting food and beverages contaminated by contact with a disease reservoir is another example of disease transmission by indirect contact. The fecal-oral route of transmission, in which sewage-contaminated water is used for drinking, washing, or preparing foods, is a significant form of indirect transmission, especially for gastrointestinal diseases such as cholera, rotavirus infection, cryptosporidiosis, and giardiasis.

These modes of transmission are all examples of horizontal transmission because the infectious agent is passed from person to person in a group. Some diseases also are transmitted vertically; that is, they are transmitted from parent to child during the processes of reproduction (through sperm or egg cells), fetal development, or birth. Diseases in which vertical transmission occurs include AIDS and herpes encephalitis (which occurs when an infant contracts the herpes simplex type II virus during birth).

6.4. Host defenses against infectious diseases

Overview of the immune system

The immune system is the body's biological defense mechanism that protects against foreign invaders. The true roots of the study of the immune system date from 1796 when an English physician, Edward Jenner, discovered a method of smallpox vaccination. He noted that dairy workers who contracted cowpox from milking infected cows were thereafter resistant to smallpox. In 1796, Jenner injected a young boy with material from a milkmaid who had an active case of cowpox. After the boy recovered from his own resulting cowpox, Jenner inoculated him with smallpox; the boy was immune. After Jenner published the results of this and other cases in 1798, the practice of Jennerian vaccination spread rapidly.

In addition Louis Pasteur who established the cause of infectious diseases and the medical basis for immunization. Pasteur formulated his germ theory of disease, the concept that disease is caused by communicable microorganisms. In 1880, Pasteur discovered that aged cultures of fowl cholera bacteria lost their power to induce disease in chickens but still conferred immunity to the disease when injected. He went on to use attenuated (weakened) cultures of anthrax and rabies to vaccinate against those diseases.

The immune system is composed of a number of different cell types, tissues and organs. Many of these cells are organized into separate lymphoid organs or glands. Since attack from microbes can come at many different sites of the body, the immune system has a mobile force of cells in the bloodstream that are ready to attack the invading microbe wherever it enters the body.

Although many of the cells of the immune system are separate from each other, they maintain communication through cell contact and molecules secreted by them. For this reason the immune system has been likened to the nervous system.

The human body has several general mechanisms for preventing infectious diseases. Some of these mechanisms are referred to as nonspecific or innate defenses because they operate against a wide range of pathogens. Other mechanisms are referred to as specific or adaptive defenses because they target particular pathogens and pathogen-infected cells.

Nonspecific mechanisms (Innate Immune system)

Self-test

1. *Explain about anatomical and physiological barriers of human body*
2. *What is inflammation?*

Nonspecific mechanisms are the body's primary defense against disease. The Innate immune system is the first line of defense which is present at birth and changes little throughout the life of an individual. The cells and molecules of this innate system are mainly responsible for the first stages of expulsion of the microbe. These mechanisms include anatomical barriers to invading pathogens, physiological deterrents to pathogens, phagocytosis, inflammation and the presence of normal flora. An example of an anatomical barrier is the nasal opening to the respiratory system. This natural opening is a long, convoluted passage covered by mucous membranes that trap airborne particles and prevent most of them from reaching the lungs. Other anatomical barriers are the skull and vertebral column, which protect the central nervous system few pathogens are able to penetrate bone. The skin also is a major anatomical barrier to microorganisms. The surface layer of dead, hardened cells is relatively dry, and skin secretions make the surface somewhat acidic. When sweat evaporates, salt is left behind on the skin. All of these conditions (low moisture, low pH, and high salinity) prevent most microorganisms from growing and multiplying on the skin. The major medical challenge in treating burn patients is preventing and treating infections that result because of the absence of skin that ordinarily would prevent invasion of microorganisms.

Natural openings also are protected by a variety of physiological deterrents. For example, tears continually flush debris from the eyes. Vaginal secretions are acidic, a hostile environment that discourages the growth of many pathogens. The eye, mouth, and nasal openings are protected by tears, saliva, or nasal secretions that contain lysozyme, an enzyme that breaks down bacterial cell walls. Blood, sweat, and some tissue fluids contain lysozyme as well. In addition to lysozyme, the blood has many elements that defend the body from disease-causing organisms. The white blood cells include several types of phagocytic cells that detect, track, engulf, and kill invading bacteria and viruses, as well as infected host cells and other debris. These phagocytic cells are part of the nonspecific immune system. Blood plasma also includes clotting factors that initiate a clot at the injury site, preventing pathogens from invading the body further. Finally, the complement proteins in the blood participate in a cascade of molecular events that result in inflammation, the release of molecules that stimulate phagocytic cells, and the formation of a complex of proteins that binds to the surface of bacterial or infected host cells and lyses those cells.

The inflammatory response is another nonspecific defense mechanism that helps to prevent infectious agents from spreading in the body. Inflammation involves swelling, reddening, elevated temperature, and pain. Unfortunately, inflammation itself frequently causes tissue damage and, in severe cases, even death.

Finally, the protective role of the "normal flora" of microorganisms present on and in the body should not be overlooked. These organisms survive and grow on the skin and in the mouth, gastrointestinal tract, and other areas of the body, but do not cause disease because their growth is kept under control by the host's defense mechanisms and by the presence of other microorganisms. These organisms protect the host by successfully competing with disease-causing organisms, preventing the latter from invading host tissues. When the growth of the normal flora is suppressed (for example, due to antibiotic treatment), other "opportunistic" agents that normally does not grow in or on the body may be able to infect and cause disease.

Summary

The Innate immune system is the first line of defense' which is present at birth and changes little throughout the life of the individual. The cells and molecules of this innate system are mainly responsible for the first stages of expulsion of the microbe.

Some of the most important cells in the innate immune system are phagocytes, since they are able to ingest and kill microbes. In general the innate immunity includes:-

- *Anatomical and physiological barriers*

- *Cellular defense (phagocytosis and extracellular killing)*
- *Inflammation*
- *The complement system*
- *Normal flora*

Specific mechanisms of host resistance (Adaptive defense)

Self-test

1. *What is the main difference between T and B lymphocytes?*
2. *Explain about helper and killer T cells*
3. *What are antibodies?*

When these nonspecific mechanisms fail, the body initiates a second, specific line of defense. Adaptive immune system is brought into action even as the innate immune system is dealing with the microbe, and especially if it is unable to remove the invading microbe. The key difference between the two systems is that the adaptive system shows far more specificity and remembers that a particular microbe has previously invaded the body. This leads to a more rapid expulsion of the microbe on its second and third time of entry.

This specific immune response enables the body to target particular pathogens and pathogen-infected cells for destruction. It depends on specialized white blood cells called lymphocytes and includes T-cells (produced from lymphocytes that matured in the thymus gland) and B-cells (produced from lymphocytes that matured in the bone marrow).

The two complementary components of the specific immune response are the cell-mediated response and the antibody-mediated response. The cell-mediated response involves T-cells and is responsible for directly destroying body cells that are infected with a virus or have become cancerous, or for activating other immune cells to be more efficient microbe killers. The antibody-mediated response involves both T-cells and B-cells and is critical for the destruction of invading pathogens as well as the elimination of toxins.

Both the cell-mediated and antibody-mediated responses are initiated after a particular type of phagocytic cell, a macrophage, engulfs a pathogen. Macrophages digest the pathogen and then display antigens from the pathogen on their surface. Antigens are specific molecules, such as the proteins on the surface of pathogens, which elicit an immune response. This display helps the macrophages stimulate specific helper T-cells to release signal molecules called lymphokines. The lymphokines, in turn, stimulate the cell-mediated and antibody-mediated responses.

The cell-mediated response occurs when the lymphokines released from the helper T-cells stimulate other cell types to participate in the immune response. Lymphokine-stimulated killer T-cells attach to the pathogen-infected cells and destroy them, whereas lymphokine-activated phagocytic cells produce more toxic molecules that can kill the pathogen directly.

The antibody-mediated response occurs when the lymphokines activate specific B-cells to produce antibodies (proteins that specifically recognize and bind to antigens). These antibodies attach to antigens on the surface of the pathogens and signal attack by phagocytic cells and complement system. Other B-cells go on to become memory B-cells, which respond quickly by producing more antibodies upon subsequent infection.

The branches of acquired immunity:-

I. Humoral or Antibody-mediated immunity

- Consists of antibodies circulating in the fluids of the body
- Targets are mainly extracellular microbes and parasites
- Produced by B-lymphocytes

II. Cellular or Cell-mediated immunity

- Mediated by lymphocytes (T-cells) themselves
- Targets – virus or parasite-infected cells, cancer cells, foreign graft cells
- Can act directly by lysing foreign cells or indirectly by releasing chemicals that enhance the inflammatory response or activate other lymphocytes or macrophages.

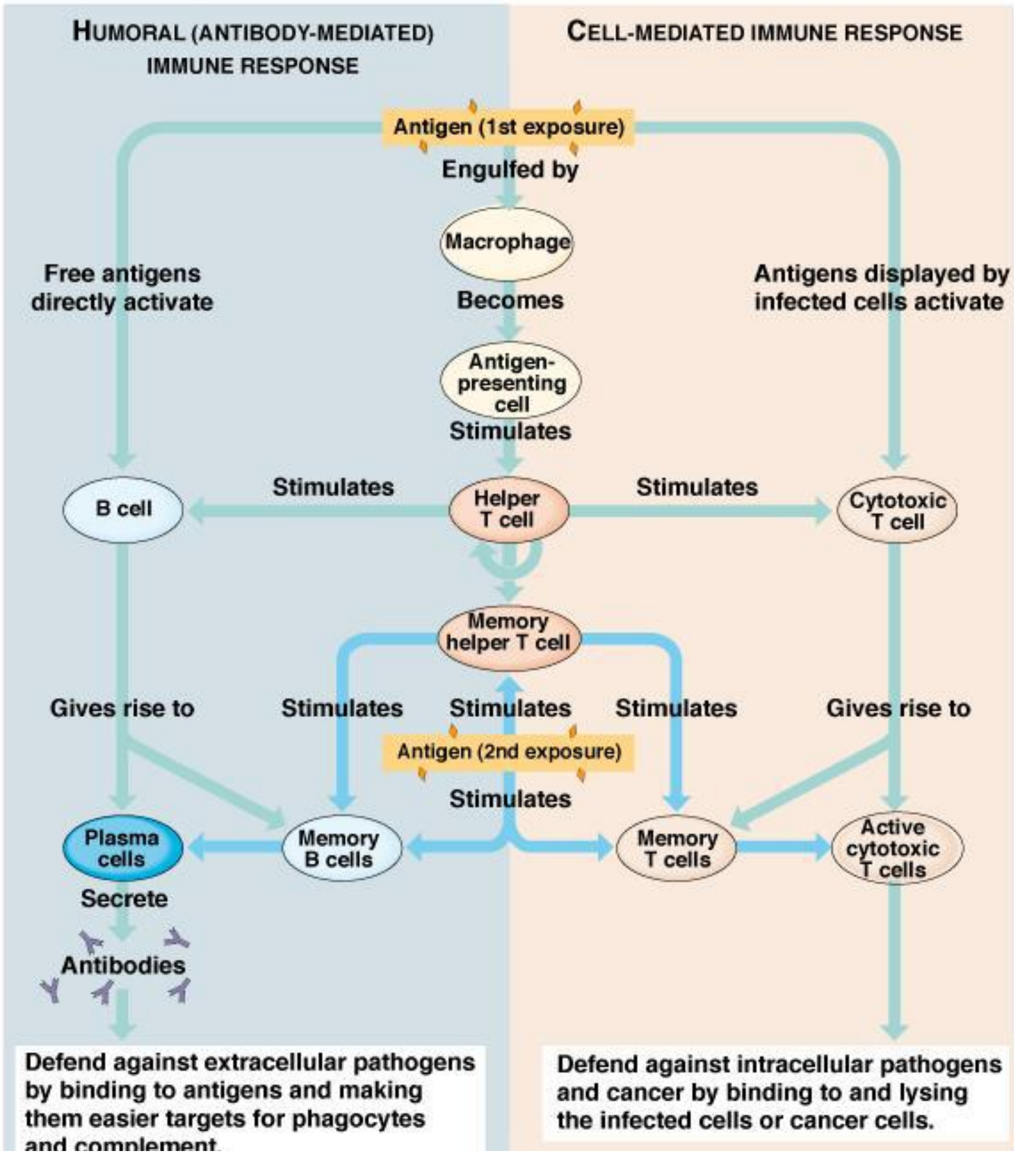


Fig: 6.2 overview of cell-mediated and antibody-mediated immune responses

Interaction between innate and adaptive immunity

The innate and adaptive immune systems have different types of cells and molecules, which are responsible for the two different types of immune systems. In addition they have different characteristics as it is explained above:-

The cells, molecules and characteristics of innate and adaptive immune systems are summarized in the table below.

Table 6.1. The innate and adaptive immunity

Characteristics	**Cells**	**Molecules**
Innate immunity		
Responds rapidly Present at birth Has no specificity No memory Mast cells	Phagocytes (PMNs and macrophages) Dendritic cells Natural killer cells	Cytokines Complement Acute phase proteins
Adaptive immunity		
Highly specific Slow to start Has Memory Adaptiveness	T and B cells	Antibodies Cytokines

Although innate and adaptive immunity are often considered separately for convenience and to facilitate their understanding, it is important to recognize that they frequently work together. The various cells of both systems work together through direct contact with each other, and through interactions with chemical mediators, the cytokines and chemokines.

Here are some examples:-

1. Macrophages are responsible to phagocytsis the infectious microbes and at the same time produce important **cytokines** that help to induce the adaptive immune response.
2. Complement components of the innate immune system can be activated directly by microbes, but can also be activated by antibodies, molecules of the adaptive system.

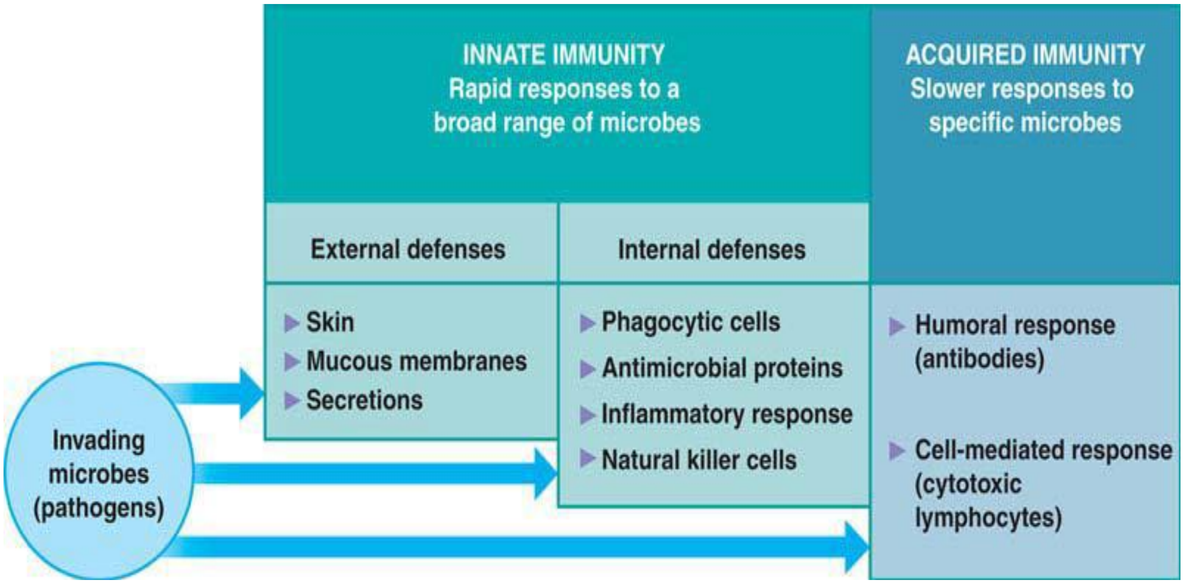


Fig. 6.3 Patterns and layers of responses against pathogens

Activity

1. *What is the main difference between innate and adaptive immune response?*
2. *Explain the process of Phagosytosis?*
3. *What makes normal flora to become opportunistic pathogen?*
4. *What is the difference between cellular and hum moral arm of immunity?*

6.5. Adverse immune reactions (responses)

The aim of the immune responses is to protect the body from damage from any environmental agents including pathogens and also from cancer, but adverse immunological reactions can occur and cause adverse effects. In the other way adverse immunological reactions can occur and cause adverse effects to the host due to: Exaggerated immune response and/or producing inappropriate immune response against self-components is due to failure of appropriate recognition mechanism. It May leads to different forms of tissue damage. In this there is a Production of more damage than it prevents, immune responses (especially to some antigens) can lead to more severe tissue damaging reactions (immunopathology). This kind of immune disorder can be divided as hypersensitivity and autoimmunity.

In general, there are three types of immunological disorders.

- Hypersensitivity
- Autoimmune diseases

- Immunodeficiency

6.5.1. Hypersensitivity reactions

An immune response to antigen causes inappropriate and/or excessive tissue damage (harmful to the host). Hypersensitivity is the over reactivity by the immune system to antigens. Hypersensitivity reactions are antigen specific and occur after the immune system has already responded to an antigen.

There are four types of hypersensitivity reactions: Type I, Type II, Type III and Type IV. The Types I, II and III are antibody or immune complex mediated occurring within minutes or hours after a sensitized individual re-encounters the same antigen. Type IV is cell mediated (Delayed type hypersensitivity (DTH)). Occurs days after re-encountering the antigen.

Type I Hypersensitivity

Type I reactions (immediate hypersensitivity) are IgE-mediated**.** Antigen binds to IgE that is bound to tissue mast cells and blood basophils, triggering release of preformed mediators (eg, histamine, proteases, chemotactic factors) and synthesis of other mediators (eg, prostaglandins, leukotrienes, platelet-activating factor, cytokines). These mediators cause vasodilation, increased capillary permeability, mucus hypersecretion, smooth muscle spasm, and tissue infiltration with eosinophils, type 2 helper T (TH2) cells, and other inflammatory cells. Type I reactions develop 1 hour after exposure to antigen.

Type I hypersensitivity reactions underlie all atopic disorders (eg, atopic dermatitis, allergic asthma, rhinitis, conjunctivitis) and many allergic disorders (eg, anaphylaxis, some cases of angioedema, urticaria, latex and some food allergies). The terms atopy and allergy are often used interchangeably but are different:

- **Atopy** is an exaggerated IgE-mediated immune response; all atopic disorders are type I hypersensitivity disorders.
- **Allergy** is any exaggerated immune response to a foreign antigen regardless of mechanism.

Thus, all atopic disorders are considered allergic, but many allergic disorders (eg, hypersensitivity pneumonitis) are not atopic. Allergic disorders are the most common disorders among people.

Type II Hypersensitivity

Type II reactions (antibody-dependent cytotoxic hypersensitivity) result when antibody binds to cell surface antigens or to a molecule coupled to a cell surface. The antigen-antibody complex activates cells that participate in antibody-dependent cell-mediated cytotoxicity (eg, natural killer cells, eosinophils, and macrophages), complement, or both. The result is cell and tissue damage. The disorders involving type II reactions include hyperacute graft rejection of an organ transplant, Coombs-positive hemolytic anemias, Hashimoto thyroiditis, and anti–glomerular basement membrane disease (eg, Goodpasture syndrome).

- Example for type II hypersensitivity

Rhesus Incompatibility

Rhesus D (RhD) antigen is carried by erythrocytes. Children born to RhD^{-} mothers and RhD^{+} fathers may express RhD on their erythrocytes. Prior to pregnancy, the mother can become sensitized to RhD antigen through blood transfusion and during pregnancy and especially at birth by the baby's RhD^{+} erythrocytes coming into contact with the mother's immune system. Some pass across the placenta but most are released into the maternal circulation during placental shedding. Since RhD is not present in the mother, her immune system responds to it as a foreign antigen and makes antibodies (*Fig.6.4*). This is usually not a problem during the first pregnancy but in subsequent pregnancies small amounts of erythrocytes passing across the placenta stimulate a memory response leading to specific anti-RhD antibody production. IgG antibodies pass across the placenta and bind to the fetal erythrocytes leading to their opsonization and lysis. This results in hemolytic anemia of the newborn if not prevented. This is often call hemolytic disease of the newborn.

Generally, mothers at risk are detected during early stages of pregnancy and monitored thereafter. At termination of each pregnancy with an RhD^{+} fetus, $RhD(^{-})$ mothers are given antibodies to RhD which is thought to remove the fetal erythrocytes from the blood stream and suppress the development of a subsequent immune response.

Blood transfusion

It is common practice to give blood transfusions in cases of severe blood loss. The major blood group antigens A and B are expressed at the surface of erythrocytes and we have natural antibodies (mostly IgM) to these antigens. Individuals who are blood group A have antibodies to B antigens, those who are blood group B will have anti-A antibodies and those who are AB will have neither. Those who are blood group O will have both antibodies. It is therefore important to do blood group typing on transfusion donors and recipients. In most cases, this is done accurately but occasionally accidents occur whereby blood is given to a recipient who has the reactive isohemagglutinins. This can result in a transfusion reaction which manifests itself as (a complement mediated) massive intravascular life-threatening hemolysis.

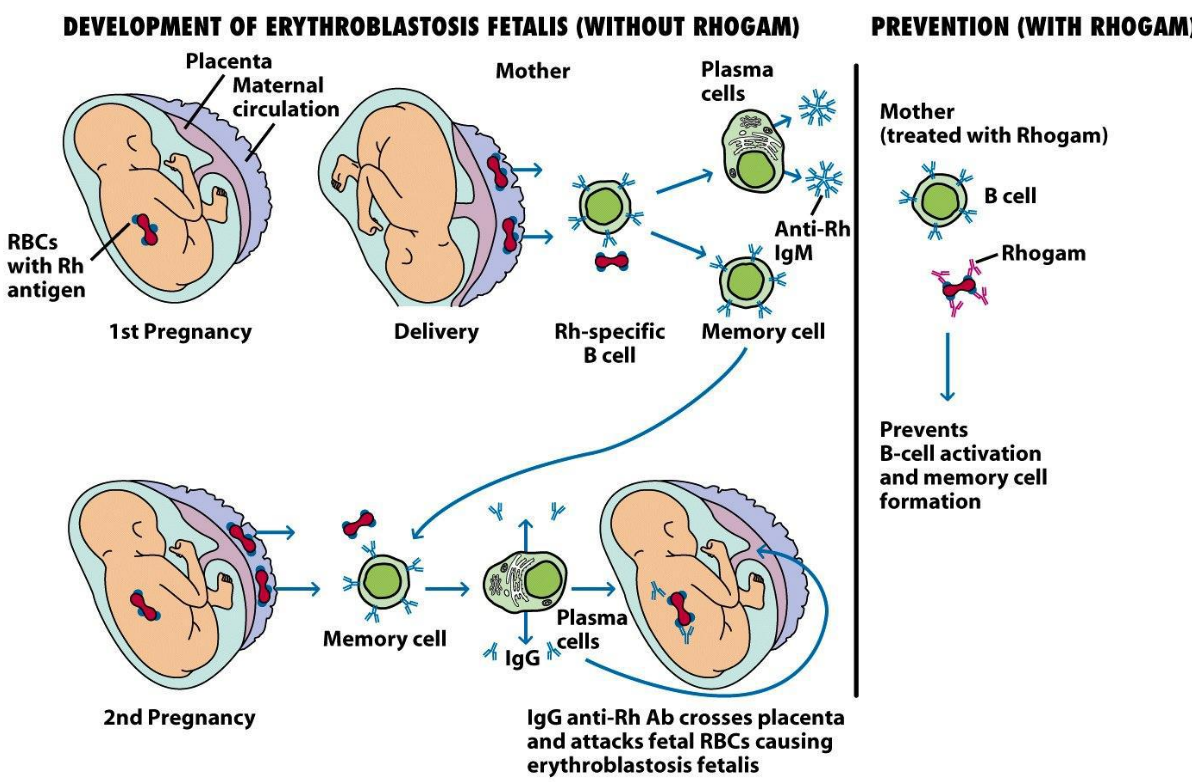


Fig. 6.4. Rh factor and pregnancy

Type III Hypersensitivity

Type III reactions (immune complex disease) cause inflammation in response to circulating antigen-antibody immune complexes deposited in vessels or tissue. These complexes can activate the complement system or bind to and activate certain immune cells, resulting in release of inflammatory mediators.

Consequences of immune complex formation depend in part on the relative proportions of antigen and antibody in the immune complex. Early, there is excess antigen with small antigen-antibody complexes, which do not activate complement. Later, when antigen and antibody are more balanced, immune complexes are larger and tend to be deposited in various tissues (eg, glomeruli, blood vessels), causing systemic reactions.

Type III reactions develop 4 to 10 days after exposure to antigen and, if exposure to the antigen continues, can become chronic. Type III disorders include serum sickness, systemic lupus erythematosus(SLE), rheumatoid arthritis(RA), leukocytoclastic vasculitis, cryoglobulinemia, acute hypersensitivity pneumonitis, and several types of glomerulonephritis.

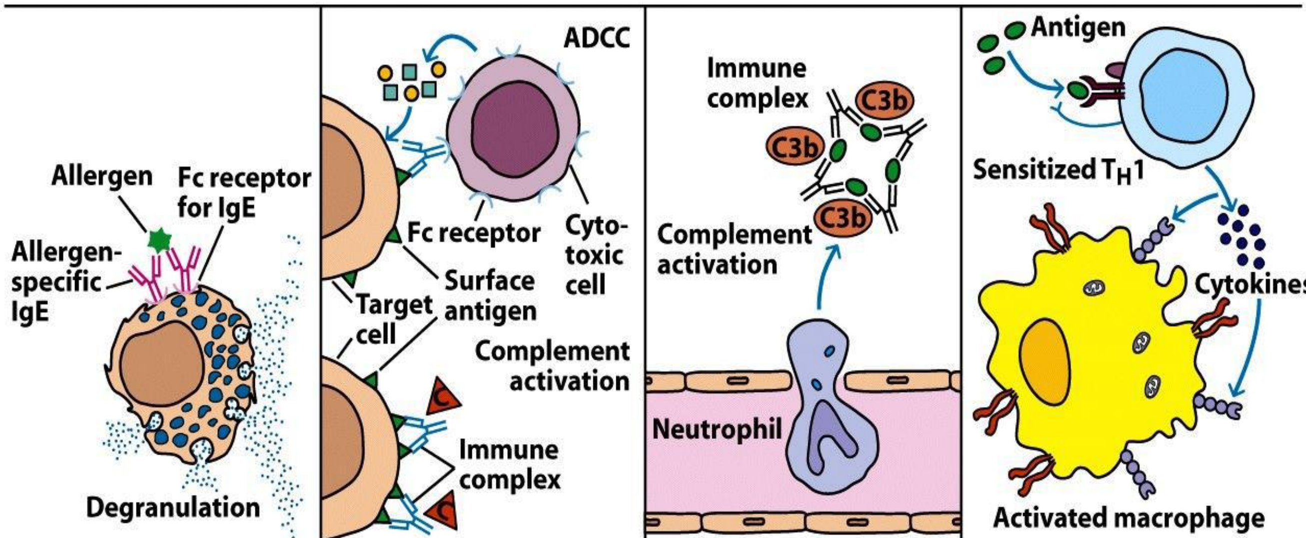
Type IV Hypersensitivity

T cells, sensitized after contact with a specific antigen, are activated by continued exposure or re exposure to the antigen; they damage tissue by direct toxic effects or through release of cytokines, which activate T cells, together with dendritic cells eosinophils, monocytes and macrophages, neutrophils, or natural killer cells. This hypersensitivity starts from 24 h after contact with an antigen. Disorders involving type IV reactions include contact dermatitis (eg, poison ivy), subacute and chronic hypersensitivity pneumonitis, allograft rejection, the immune response to tuberculosis, and many forms of drug hypersensitivity.

Examples:-*Mycobacterium tuberculosis* – the bacteria survive within macrophages, which is the tuberculin reaction

- This is a 'recall' response to purified mycobacterial antigens and is used as the basis of a skin test for an immune response (not necessarily curative) to TB.

- The inability to kill all mycobacteria in macrophages by T cells often results in a chronic stimulation of the mycobacterial specific T cells.
- The cytokines produced are responsible for 'walling off' the macrophages containing the persistent antigens and thus the production of granulomas.



Type I	Type II	Type III	Type IV
IgE-Mediated Hypersensitivity	IgG- or IgM-Mediated Cytotoxic Hypersensitivity	Immune Complex–Mediated Hypersensitivity	Cell-Mediated Hypersensitivity
Ag induces cross-linking of IgE bound to mast cells and basophils with release of vasoactive mediators.	Ab directed against cell surface antigens meditates cell destruction via complement activation or ADCC.	Ag-Ab complexes deposited in various tissues induce complement activation and an ensuing inflammatory response mediated by massive infiltration of neutrophils.	Sensitized T_H1 cells shown above release cytokines that activate macrophages or T_C cells that mediate direct cellular damage. T_H2 cells and CTLs mediate similar responses.
Typical manifestations include systemic anaphylaxis and localized anaphylaxis such as hay fever, asthma, hives, food allergies, and eczema.	Typical manifestations include blood transfusion reactions, erythroblastosis fetalis, and autoimmune hemolytic anemia.	Typical manifestations include localized Arthus reaction and generalized reactions such as serum sickness, necrotizing vasculitis, glomerulonephritis, rheumatoid arthritis, and systemic lupus erythematosus.	Typical manifestations include contact dermatitis, tubercular lesions, and graft rejection.

Fig. 6.5. Types of hypersensitivity reactions (*source, Kuby immunology*)

6.5.2. Autoimmunity and autoimmune disease

Self-test

1. What are the factors responsible for autoimmune diseases?

2. What do we mean by self tolerance

Autoimmunity is an acquired immune reactivity to self antigens which lead to tissue damage. Normally, the immune system can tell the difference between foreign cells and your own cells. In the case of an autoimmune disease, the immune system mistakes part of your body, like joints or skin, as foreign. It releases proteins called auto-antibodies that attack healthy cells. In short autoimmune diseases arise as the result of a breakdown in self-tolerance. Some autoimmune diseases target only one organ. Type 1 diabetes damages the pancreas. Other diseases, like systemic lupus erythematosus (SLE), affect the whole body. There are more than 80 different autoimmune diseases but here are 14 of the most common ones.

Type 1 diabetes:-The pancreas produces the hormone insulin, which helps regulate blood sugar levels. In type 1 diabetes mellitus, the immune system attacks and destroys insulin-producing cells in the pancreas. High blood sugar results can lead to damage in the blood vessels, as well as organs like the heart, kidneys, eyes, and nerves.

Rheumatoid arthritis (RA):-In rheumatoid arthritis (RA), the immune system attacks the joints. This attack causes redness, warmth, soreness, and stiffness in the joints. Unlike osteoarthritis, which commonly affects people as they get older, RA can start as early as your 30s or sooner.

Psoriasis/psoriatic arthritis:- Skin cells normally grow and then shed when they're no longer needed. Psoriasis causes skin cells to multiply too quickly. The extra cells build up and form inflamed red patches, commonly with silver-white scales of plaque on the skin. Some people with psoriasis also develop swelling, stiffness, and pain in their joints. This form of the disease is called psoriatic arthritis.

Multiple sclerosis:-Multiple sclerosis (MS) damages the myelin sheath, the protective coating that surrounds nerve cells, in your central nervous system. Damage to the myelin sheath slows the transmission speed of messages between your brain and spinal cord to and from the rest of your body.

This damage can lead to symptoms like numbness, weakness, balance issues, and trouble walking. The disease comes in several forms that progress at different rates. According to a 2012 study Trusted Source, about 50 percent of people with MS need help for walking within 15 years after the disease starts.

Systemic lupus erythematosus (SLE):-Although doctors in the 1800s first described lupus as a skin disease because of the rash it commonly produces, the systemic form, which is most the common, actually affects many organs, including the joints, kidneys, brain, and heart. Joint pain, fatigue, and rashes are among the most common symptoms.

Inflammatory bowel disease:-Inflammatory bowel disease (IBD) is a term used to describe conditions that cause inflammation in the lining of the intestinal wall. Each type of IBD affects a different part of the GI tract.

Crohn's disease can inflame any part of the GI tract, from the mouth to the anus.

Ulcerative colitis affects only the lining of the large intestine (colon) and rectum.

Addison's disease:-Addison's disease affects the adrenal glands, which produce the hormones cortisol and aldosterone as well as androgen hormones. Having too little of cortisol can affect the way the body uses and stores carbohydrates and sugar (glucose). Deficiency of aldosterone will lead to sodium loss and excess potassium in the bloodstream. Symptoms include weakness, fatigue, weight loss, and low blood sugar.

Graves' disease:-Graves' disease attacks the thyroid gland in the neck, causing it to produce too much of its hormones. Thyroid hormones control the body's energy usage, known as metabolism. Having too much of these hormones revs up your body's activities, causing symptoms like nervousness, a fast heartbeat, heat intolerance, and weight loss.

One potential symptom of this disease is bulging eyes, called exophthalmos. It can occur as a part of what is called Graves' ophthalmopathy, which occurs in around 30 percent of those who have Graves' disease, according to a 1993 study Trusted Source.

Sjogren's syndrome:-This condition attacks the glands that provide lubrication to the eyes and mouth. The hallmark symptoms of Sjogren's syndrome are dry eyes and dry mouth, but it may also affect the joints or skin.

Hashimoto's thyroiditis:-In Hashimoto's thyroiditis, thyroid hormone production slows to a deficiency. Symptoms include weight gain, sensitivity to cold, fatigue, hair loss, and swelling of the thyroid (goiter).

Myasthenia gravis:-Myasthenia gravis affects nerve impulses that help the brain control the muscles. When the communication from nerves to muscles is impaired, signals can't direct the muscles to contract. The most common symptom is muscle weakness that gets worse with activity and improves with rest. Often muscles that control eye movements, eyelid opening, swallowing, and facial movements are involved.

Autoimmune vasculitis:-Autoimmune vasculitis happens when the immune system attacks blood vessels. The inflammation that results narrows the arteries and veins, allowing less blood to flow through them.

Pernicious anemia:- This condition causes deficiency of a protein, made by stomach lining cells, known as intrinsic factor that is needed in order for the small intestine to absorb vitamin B-12 from food. Without enough of this vitamin, one will develop an anemia, and the body's ability for proper DNA synthesis will be altered.

Pernicious anemia is more common in older adults. According to a 2012 study, it affects 0.1 percent of people in general, but nearly 2 percent of people over age 60.

Celiac disease People with celiac disease can't eat foods containing gluten, a protein found in wheat, rye, and other grain products. When gluten is in the small intestine, the immune system attacks this part of the gastrointestinal tract and causes inflammation.

Factors contributing for autoimmune diseases:

- **Age**, Auto-antibodies are more prevalent in older people and
- **Gender** women have a greater risk than men for developing an autoimmune disease.
- **Genetic factor** Antigen-specific autoimmune phenomena cluster in certain families.
  - Particular HLA genes are associated with certain autoimmune diseases
- **Infections**
  - Many infectious agents (EBV, mycoplasma, streptococci, klebsiella, malaria, etc.)

  - Have been linked to particular autoimmune diseases and may be important in their etiology.
- **Nature of the auto antigen.**
  - Target antigens are often highly conserved proteins such as heat shock proteins (HSPs), stress proteins, enzymes, or their substrates.

6.5.3. Immune Deficiencies

The immunological disorders can be caused by the deficiency of immune response of the host body or the excessive production of the host immune system. Immune deficiencies occur when one or more components of the immune system are defective. It is classified as primary or secondary.

Primary immunodeficiency

It is congenital because of genetic disorder, which caused by mutations affecting any of a large number of genes that control the expression and activities of immune responses. Most present in clinic as a recurrent or overwhelming infections in very young children. May affect either the acquired or innate immune system. In other way this defect can affect in either the lymphoid or the myeloid lineages.

Defects in lymphoid lineage:- May involve B-cell, T-cell or both. The severity depends on the number and type of immune components involved.

- **B- Cell immunodeficiency**: associated with recurrent bacterial infections but may be normal immunity to viruses and fungi.

- **T-cell deficiencies**: can affect both cell and humoral immunity. Do not response to various types of pathogens.

Defects in myeloid linage: Affect innate immunity, especially phagocytic activity.

- Chronic granulomatos disease (CGD). It leads to recurrent or persistent intracellular infections and granuloma formation. Genetically heterogeneous deficiency disorder resulting from the inability of phagocytes to kill microbes they have ingested. Have a higher prevalence of mucosal inflammatory disorders such as colitis, enteritis, etc.

- Complement deficiencies, this one associated with increased susceptibility to bacterial or fungal infection and/or immune complex disease.

Secondary immunodeficiency

This type is acquired secondary to some agents after birth, more common in malnutrition, infection, cancer, etc. Patients treated by immunosupressive drugs. The good example is HIV that causes AIDS.

Activity

1. What is the main difference between hypersensitivity and autoimmunity?

2. Give example for each of the four types of hypersensitivity

3. Give at least four examples of common systemic autoimmune diseases

4. Explain about how HIV/AIDs results in immune-deficiency

6.6. Tumor Immunolology

Self test

1. What is the different between cancer and tumor cells?

2. What are the important antigens to produce tumor immunity?

A **tumor** is a mass of tissue that's formed by an accumulation of abnormal cells. **Tumor** cells grow, even though the body does not need them, and unlike normal old cells, they don't die.

Cancer is a disease in which cells, almost anywhere **in the** body, begin to divide uncontrollably. A **tumor** is when this uncontrolled growth occurs in solid tissue such as an organ, muscle, or bone. **Tumors** may spread to surrounding tissues through the blood and lymph systems.

Most **cancers** form a lump called a **tumor** or a growth. Lumps that are not **cancer** are called benign. Lumps that **are cancer** are called malignant. There are some **cancers**, like leukemia (**cancer** of the blood), that don't form **tumors.**

Tumor immunology immune surveillance is a concept that envisages prevention of the development of the most tumors through early destruction of abnormal cells by the host's immune system. Surveillance probably acts against viruses not tumors. The evidence for this is that although there is an increased incidence of tumors in immuno-suppressed individuals, the most dramatic increase is in tumors associated with oncogenic viruses. Cellular responses to tumor-associated antigens occur; the antigens may be virus coded, or they may be altered or over-expressed host genes are produced. Differentiated antigens expressed on tumor can be detected by monoclonal antibodies or patients' sera. Although the antigens are no restricted to tumor cells, they are useful for diagnosis and may be targets for antibody-mediated therapy. Passive immunotherapy with monoclonal antibodies is promising when single cells are targeted or the problem of poor penetration into tumor masses can be circumvented. Immunotherapy by active immunization or by passive transfer of cells is still largely experimental, because of tumor escape mechanisms. Cytokines are active against a few tumor types.

6.6.1. Evidence for immune reactivity to tumor

There is a lot of evidence that tumors can elicit an immune response. Such evidence includes:

- Tumors that have severe mononuclear cell infiltration have a better prognosis than those that lack it.
- Certain tumors regress spontaneously (e.g., melanomas, neuroblastomas), suggesting an immunological response.
- Some tumor metastases regress after removal of primary tumor which reduces the tumor load, thereby inducing the immune system to kill the residual tumor.
- Although chemotherapy leads to rejection of a large number of tumor cells, the few tumor cells that evade the action of the drugs can outgrow and kill the host. However, the immune system may be able to mount an attack against the few tumor cells that are spared by the chemotherapeutic agent.
- There is an increased incidence of malignancies in immuno-deficient patients such as AIDS patients who are susceptible to Kaposis sarcoma and transplant patients who are susceptible to Epstein Barr virus (EBV)-induced lymphoma.
- Tumor-specific antibodies and T lymphocytes (detected in cytotoxicity and proliferative response assays) have been observed in patients with tumors.

- The young and the old population have an increased incidence of tumors. These members of the population often have an immune system that is compromised.
- Hosts can be specifically immunized against various types of tumors demonstrating tumor antigens can elicit an immune response.

6.6.2. Tumor associated antigens

In order for the immune system to react against a tumor, the latter must have antigens that are recognized as a foreign. A number of alterations in gene expression occur in cells during tumorigenesis. Tumorigenesis may lead to expression of new antigens (neoantigens) or alteration in existing antigens that are found on normal cells. These antigens may include membrane receptors, regulators of cell cycle and apoptosis, or molecules involved in signal transduction pathways.

There are 2 main types of tumor antigens:

- Tumor-specific transplantation antigens (TSTA) which are unique to tumor cells and not expressed on normal cells. They are responsible for rejection of the tumor.
- Tumor associated transplantation antigens (TATA) that are expressed by tumor cells and normal cells.

Although chemical, UV- or virus-induced tumors express neo-antigens, the majority of these tumors are often weakly immunogenic or non-immunogenic. In most cases, TSTAs cannot be identified easily. Some of these antigens may be secreted while others may be membrane-associated molecules.

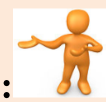
Unit 7

Taxonomy of organisms

Dear learners, this unit describes taxonomy and its etymology, an early and modern view of classification of organisms. It also deals with the major schemes of classification, concepts of kingdom and species, identification of organisms and nomenclature.

The major topics to be addressed in this unit include:

- ✓ Early attempts to classify organisms
- ✓ Modern views of classification or Schemes of classification
- ✓ Schemes of classification (the five kingdom concepts)
- ✓ Domains of life and the hierarchical system of classification
- ✓ Binomial nomenclature

Unit learning outcomes: 

Up on successful completion of this unit, you will be able to:

- ➢ describe the meaning and etymology of taxonomy.
- ➢ explain early attempts of classifying organisms.
- ➢ describe the modern views of classifying organisms.
- ➢ explain domains of Life & hierarchical system of classification.
- ➢ describe the concepts of kingdom.
- ➢ describe binomial nomenclature and its principle.
- ➢ explain different codes of binomial nomenclature.
- ➢ Describe the operative principles of nomenclature.
- ➢ explain authorities and their citation mechanisms.

Brainstorming Questions:

- What is Taxonomy?
- How diversified organisms the world are managed to be studied?
- Explain the differences between classification, nomenclature and identification.

Etymology of Taxonomy

The term taxonomy was coined by a Swiss naturalist, De Candolle, in the French form as "taxonomie" in 1813. The word taxonomy was derived from two Greek words: "taxis and nomos" which means arrangement and law respectively. Thus, taxonomy means the law governing the classification or arrangement of organisms into taxa. Taxonomy is the basic science since no start on understanding the wealth of variation can be made until some sort of classification is adopted. It is also most all-embracing and ultimate of all biological sciences because taxonomy is not complete until the data from other fields of investigation have been incorporated.

Although some naturalists use the term taxonomy as synonymous with systematics, but many naturalists consider taxonomy as one part of systematics, and it is mainly concerned with: classification, nomenclature and identification of organisms.

Classification: Is ordering/assignment of organisms into hierarchy of ranks or categories distinguished by certain characters; or based on similarities and/or differences.

Nomenclature: Is the naming of groups of organisms and the rules governing the application of the names.

Identification: Is the naming of an organism or a specimen by reference to an already existent classification. It involves referring an individual specimen to a previously classified and named system.

7.1 Early Attempts to Classify Organisms

Brainstorming questions:

1. How taxonomy is growing as a science?
2. What are the specific contributions of early naturalists for the development of modern taxonomy?

The development of modern taxonomy has not a linear path. Taxonomy was started as old as man himself. Several early Greek and Roman philosophers enumerated organisms. Some of them are discussed below:

Aristotle (384–322 BC)

Aristotle was a Greek philosopher who contributed most extensively to the development of the modern biology. Aristotle viewed life was hierarchical and he classified organisms, mainly history of Animals and other works where he showed naturalist leanings, and later more empirical works that focused on biological changes and the diversity of life. Later, Aristotle was replaced by Theophrastus and other naturalists who wrote a series of botany books that were used for many generations.

Theophrastus (370-285 BC)

He was a keen observer of mainly plants. He was the first taxonomist to write down a classification in a permanent and logical form. For this reason, he was called the father of Botany by Linnaeus. In his book "De Historia Plantarum", he classified 480 kinds of plants based on their habit. However, his work reflects the philosophy, which incorporates the principle of the rules of dichotomy or the “Excluded Middle”. Any given organisms is either A or not A. According to Theophrastus classification system, there are no any intermediate organisms. He was typologists, belief that every natural group of organisms has an invariant, generalized or idealized pattern shared by all members of the group.

Pliny the Elder (23-79 A.D.)

He was a Roman scholar and naturalist who wrote encyclopaedic books termed *Historia naturalis*, in which he mentioned and categorized plants in terms horticultural practices, medicinal uses, and timber use practices. In his classification, he used a similar classification as his predecessors' errors.

Dioscorides (1st Century AD)

He was a Greek physician who studied and described about 600 medicinal plants in his book "De Matera Medica" with their useful applications.

A. Caesalpinus (1519-1603)

In his book "De Plantis" he illustrated about 1500 plant species. He classified plants based on definite morphological criteria mainly on the basis of habit, fruits, seeds, and ovaries and their position.

J. Bauhin (1554-1631) and G. Bauhin (1560-1624)

They were brothers of Swiss botanists who worked separately but along rather similar lines. G. Bauhin produced to order the state of nomenclature which existed to some extent currently. He was also notably remembered for his recognition of genera and species as major taxonomic levels or used a binary nomenclature composed of the genus name followed by a single specific. J. P. de Tournfort (1656-1708) also carried out further Bauhin's promotion of the rank of genus with a clear explanation.

Linnaeus and Post Linnaean Classifications

Carolus Linnaeus (1707-1778), a Swede Taxonomist and Physician, was the founder of modern taxonomy both of plants and animals. The system of nomenclature that we employ today is essentially Linnaeus'. Linnaeus produced important books that he classified all known animals, plants and minerals. The two most important works are: Genera Plantarum (1737) and Species Plantarum (1753), which listed and briefly described the genera and the species. Though Linnaeus was the father of modern taxonomy, and his classification system was popular largely because its simplicity, his classification system was artificial-which depends only on few characteristics like stamens and pistil number and position.

The foundation of modern classification comes mainly after the from the works of other taxonomists M. Adanson (1727-1806), De Jussieu (1748-1836), and J. de Lamarck (1744-

1829), A.P. de Candolle and C. Darwin (1859), who never followed artificial system of Linnaeus classification.

M. Adanson (1727-1806)

Adanson is most remembered for championing the idea that in classification one should use a great range of characters covering all aspects of the organisms without placing greater emphasis on some than on others. This is called an empirical approach. Adanson was a severe critic of Linnaeus' works.

Lamarck is best known for his theory of evolution, Lamarckism, whereby characters acquired during life become inherited. DeCandolle (1778-1841) wrote a 17 volume books, in which he first introduced the word taxonomy in the French form Taxonomie. The evolutionary theory of **Darwin** (The Origin of Species by Means of Natural Selection, 1859) had little immediate impact on classifications of organisms. The previous classifications were based on morphological similarities or dissimilarities. But after Darwin work, evolutionary thinking was incorporated into classification system and population thinking came into picture.

However, the early classification systems were broad and vague as indicated by generic terms like animals, worms, sedges, grasses and trees, etcetera. Thus, the modern classification system was developed.

7.2 Modern Views of Classification (Schemes of Classification)

Brainstorming questions:

1. What are the modern views of classification?
2. How the modern views of classification are based up on?

Unlike the early classifications the modern classification system of diversified organisms is depend up on the combined evidence of morphology, ultrastructure and molecular phylogeny. In classification, though it is organisms that are being classified, their characters /character states are used to classify or categorize organisms. Different approaches have been developed to compare these characters. These differences in approach to comparison of character states are lead to the development of five different classification systems.

7.2.1. Artificial classification system

In artificial classification system, only one or at most a few characters are selected for use in making comparison among organisms. Because a few characters are involved, the difficulties encountered in describing, measuring and comparing the character states usually are minimal. Ranking is done subjectively. Artificial system is monothetic i.e. possession of unique set of characters/features is both sufficient and necessary for membership in the group defined. Artificial system was the first to be used in the classification of organisms, and Theophrastus and Linnaeus are good example of artificial system of classification.

7.2.2. Natural classification system

This classification system is based up on several to many characters selected for their value in positively correlating with character states of groups in ranks containing high information content. This system is therefore polythetic i.e. it places together organisms that have the greatest number of shared features, and no single feature is either essential to group membership or is sufficient to make an organism a member of the group. Adanson and De Jussieu are good examples of natural classification system.

7.2.3. Phyletic or Evolutionary classification system

It is a classification that aims at reconstructing a sequence starting with the most primitive character and ending with the most advanced or derived character. It ensures that each taxon recognized as a **monophyletic** i.e. has arisen by the diversification of a single ancestor. According to phyletic classification system, d decision as to which list represents the primitive and which the advanced state is made primarily by examining the fossil record to discover which character states are nowadays more common and which are less common than earlier in the fossil record.

7.2.4. Phenetics classification system

This is a classification system developed based up on numerous characters of equal weight and their comparison is using computer program. According to Harrison (1960), the word "Phenetic" is to mean a relationship by overall similarity of all available morphological characters. Thus, Similarity/resemblance is determined based on a set of phenotypic characteristics of organisms'. The following methods/approaches are used for determining the similarity of the studied organisms.

- Selection of taxa-called Operational Taxonomic Units (OTUs) for study. Thus may be species, genera or families.
- Selection of character states (minimum of 60 and 80-100 are desirable for comparision).
- Description or measurement of character states.
- Ranking of all OTUs into the categories of the taxonomic hierarchy.

7.2.5. Phylogenetic classification system

Phylogenetic or cladistics classification system is the concepts and methods of determining similarity by constructing branching patterns of evolution. The method works as follows:

- Select monophyletic taxa
- Select characters of evolutionary interest.
- Describe and/or measure character states.
- Determine homologies of characters and character states.
- Generate trees or cladograms.

Once the cladogram or tree of life is generated, it is possible to construct classification based upon the cladogram. For example, the following cladogram shows the similarity of the different organisms within the three domains.

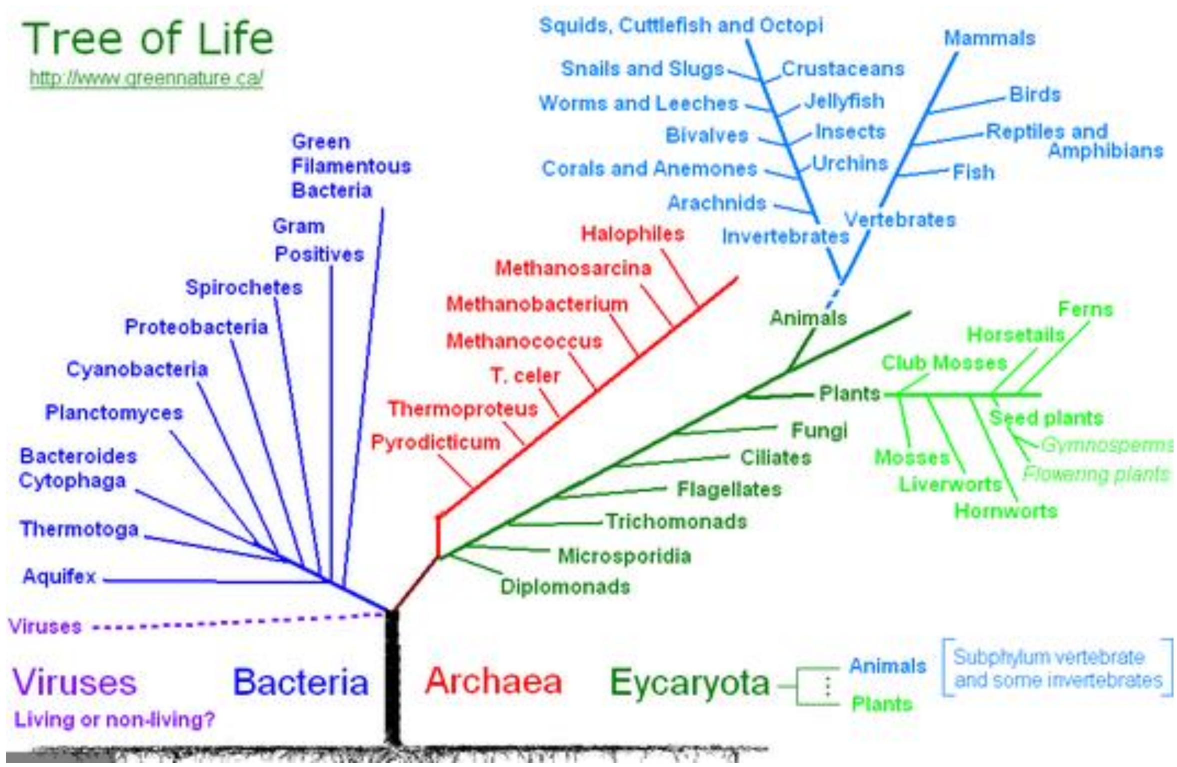


Fig: 7.1. The phylogenetic tree of life

7.3 Domains of Life and the Hierarchical System of Classification

Brainstorming questions:

1. What are the major domains of life?
2. How organisms are arranged in the hierarchical classification?
3. Discuss about the different kingdom concepts, and which organisms are categorized in each kingdom?

Linnaeus developed a hierarchical system of classification. An arrangement of taxa into an ascending series of ever–increasing inclusiveness forms is known as a hierarchical system of classification. In different levels of categories, each classifying group, called taxon (pl. taxa) is subdivided into other groups. The three domains are identified and organized based on the difference between eukaryotes and prokaryotes (Domain Archae bacteria, Eubacteria and Eukarya). Prokaryotes are extremely diverse and different from eukaryotes as proven by molecular biological studies (RNA structure) with modern technology. To understand the concepts of domains and kingdoms, see the following diagrammatical representation of mammal and insect and hierarchical classification.

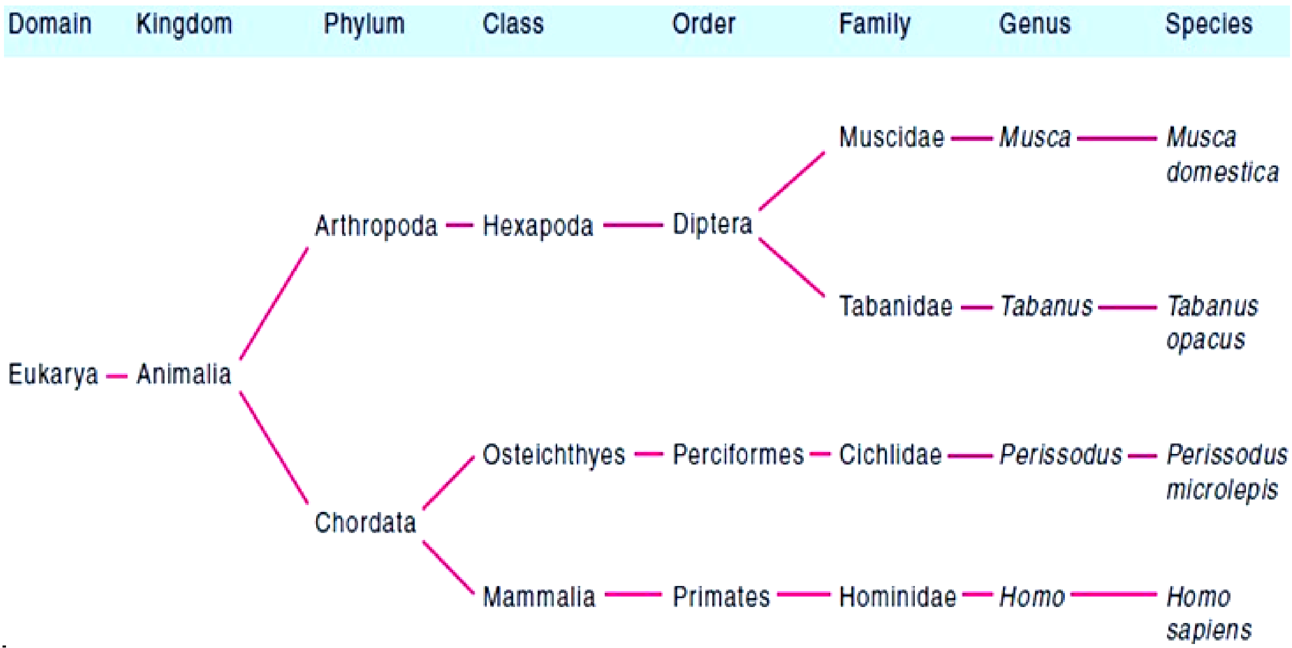


Fig: 7.2. Classification hierarchy of organism

In a hierarchical system, we start at the bottom with individuals (species) and end up at the top with one all-embracing taxon (Domain). Between the two, there are various taxa of organisms at different levels of the hierarchy, each of which is subordinate to one and one immediately higher taxon except the lowest and the highest taxon. The major levels in the hierarchy are the following:

Domain

Kingdom

Division/Phylum (pl. phyla)

Class

Order

Family

Genus (plural, genera)

Species

Species are a series of recognizably similar individuals distinct from other species; they are the fundamental bases of the hierarchy of classification. Related species are grouped in to one genus. Related genera are grouped in to one family. Related families are grouped in one order. Similarly, related orders put in one class, classes in to division (if plant) and in to phylum (if animal), and in to kingdom and domain.

7.3.1. Concepts of the Kingdom

In biology, **Kingdom** (Latin: **regnum**, pl. **regna**) is a taxonomic rank, which is the highest rank or in the more recent three-domain system, it is the second rank below the **Domain**. Kingdoms are divided into different types/approaches. These different kingdom systems were developed based on the diversity of organisms and to produce inclusive all-inclusive classification system.

The Two- Kingdom Concept/Approach

The two kingdom concept existed before the 1950s. This concept was classifying organisms based up on the cell wall present versus absent. Thus, Kingdom Plantae and Kingdom Animalia were identified. However, after the invention of the Electron Microscope, some naturalists later questioned this approach. Then the three kingdom systems were developed.

Three-Kingdom Concept

This kingdom concept/approach classifies all organisms in to three Kingdoms, namely; kingdom Plantae, Animalia and Protista (for the intermediates, like some algae and protozoa, which behave like both plants and animals. Still there are other ungrouped organisms, which lead four kingdom concepts.

The Four-Kingdom Concept

The four Kingdoms were Kingdom Plantae, Animal, Protista and Fungi. Fungi are organisms that do have both plant and animal characteristics.

The Five-Kingdom Concept

After the invention of the Transmission Electron Microscope (has a very high-resolution power- up to 100000x), some biologists were able to investigate the composition of the cell. The microscope revealed that there are differences in the composition of the cells of few groups of organisms that were considered members of the Kingdom Plantae, and some members of the Kingdom Animalia. Thus, they suggested the Five Kingdom approaches; which are: kingdom Monera, kingdom Fungi, kingdom Protista, kingdom Plantae and kingdom Animalia.

The Six-Kingdom Concept

This concept classifies first kingdom monera in to two groups based on the nucleus and other organelles have or lacking a membrane. Thus, the six kingdom system was developed, and these are: kingdom Archaebacteria, Eubacteria, Protista, Fungi, Plantae and Animalia (Figure 7.3).

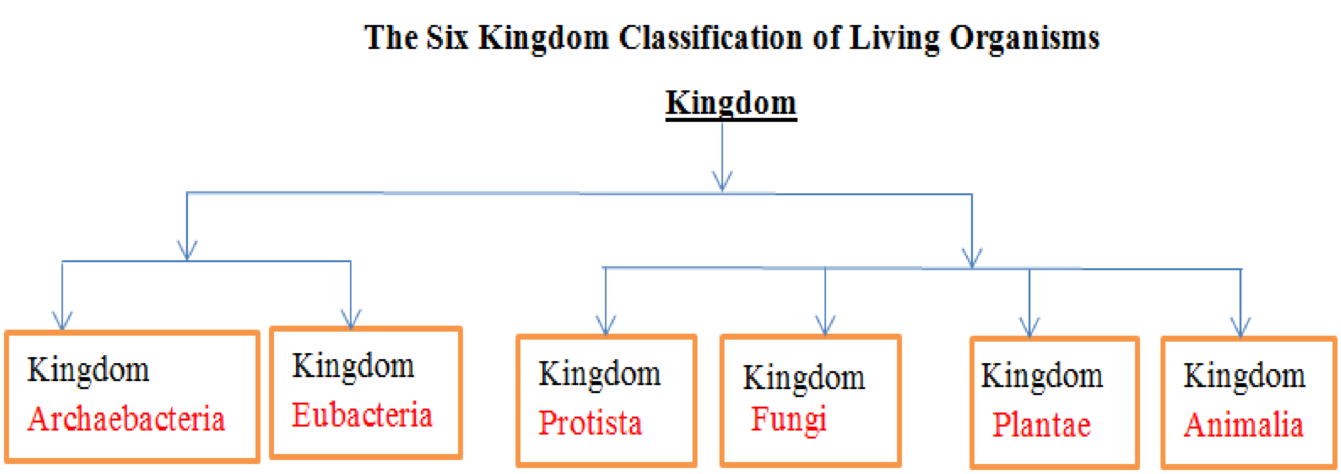


Fig: 7.3. The six kingdom systems

7.4 Binomial Nomenclature

Brainstorming questions:

1. What is the binomial nomenclature?
2. How the binomial nomenclature is applicable for organisms?
3. What are the preconditions for giving binomial nomenclature for organisms?
4. What is the purpose of giving scientific names for organisms?
5. What are characteristics scientific names?
6. What are operative principles of nomenclature?
7. How authorities of scientific names are cited?

Nomenclature is the naming of organisms and the rules governing the application of these names. The rules of nomenclature begin from Linnaus's of classification where he established the real beginning of a perfect nomenclature of organisms. Especially binomial nomenclature was practicable after Linnaeus wrote the books "*Species Plantarum and Genera Plantarum*". In nomenclatural system, each organism is designated by two names, the first is the name of the genus; the second is the specific epithet. No two species can have the same name. The names are always Latin (or Latinized) and the genus is capitalized while species name is not.

7.4.1. The Purpose of giving names to organisms

Name is a conventional symbol or code that serves as a means of reference and avoids the need for continuous use of an inconvenient descriptive phrase. Giving name for an organism is used for act as vehicle of communication, to universalize the organism and to avoid any names. In the world, there are many languages, and many of them use different alphabets. Even within a single language the same name is often used in different senses to denote different kinds of organisms, or same organism is known by more than one name. Thus, the Code of nomenclature tries to avoid the defects of vernacular names and for this reason sets of rules have been drawn up. Scientific names are written in Latin form as well as in Latin alphabet. The scientific names of all living organisms are therefore Latin or are treated as Latin even if they are derived from other languages.

1.10.1.5 2.4.2. International Code nomenclature

The code is a rulebook that contains principles, rules and recommendations which form the basis of the system of nomenclature. Generally the code provides stability in the naming and classification of organisms and ensures that any given taxonomic grouping of a given rank can have only one correct name, by which the species is known. Varies international codes are established for different groups of organisms (plants, animals, fungi, bacteria, cultivated plants).

1.10.1.6 7.4.2.1. International Code Botanical Nomenclature (ICBN)

Botanical Nomenclature is the naming of groups of plants (including algae, fungi and lichens). After groups of plants have been classified names must be given to these groups so that communication about particular units will be facilitated and continuous progress in classification can be made.

7.4.2.2. International Code of Zoological Nomenclature (ICZN)

It is the system of naming animals, which applies to both living and extinct animals. The ICZN is responsible for producing the International Code of Zoological Nomenclature - a set of rules for the naming of animals and the resolution of nomenclatural problems. The primary objective of the Code is to promote the stability of the names of taxa (groups of organisms) by providing rules concerning name usage and the activity of naming new taxa.

International Code of Nomenclature of Bacteria

The International Code of Nomenclature of Bacteria (ICNB) governs the scientific names for Bacteria, including Archaea bacteria. It denotes the rules for naming taxa of bacteria, according to their relative rank. As such it is one of the Nomenclature Codes of biology. Originally the International Code of Botanical Nomenclature dealt with bacteria, and this kept references to bacteria until these were replaced in 1975. An early Code for the nomenclature of Bacteria was approved at the 4th International Congress for Microbiology in 1947. These rules are maintained by the International Committee on Systematics of Prokaryotes.

International Code of Nomenclature for Cultivated Plants

The need for a comprehensive set of practical, easily understood and internationally acceptable regulations on the naming of cultivated plants has long been evident. The International Code of Nomenclature for Cultivated Plants (ICNCP) regulates the names of cultigens (plants whose origin or selection is primarily due to intentional human activity). These are, for the most part, plants with names in the classification categories cultivar and groups. Since cultivated plants are artificial populations maintained and propagated by man, the botanical hierarchy of infraspecific categories is hardly applicable to cultivated plants. It is largely replaced by a system based on the taxonomic category cultivar. Cultivar is any assemblage of cultivated plants which is clearly distinguished by any characters and which retains its distinguishing characters when reproduced sexually or asexual. It is internationally recognized term for category of distinct cultivated sorts, which are usually called varieties. Cultivar names are preceded by the abbreviation **Cv**. or placed in single quotation marks and not Latinized names.

International Organizations & Unions for the Stabilization of Changes

At various times, taxonomists are concerned with the classification of organisms and come together at international meetings to discuss the overabundance of problems associated with nomenclature. As a result of such meetings, a set of International Commissions or Committees have been created to lay down sets of rules and recommendations covering the application of nomenclatural procedures to their particular groups of organisms. For example:

- For ICBN: International Botanical Congress;
- For ICZN: International Congress for Zoological Nomenclature.
- For Cultivated plants: The International Commission for the Nomenclature of Cultivated Plants.
- For Fungi: The International Commission for the Taxonomy of Fungi (ICTF).

However, the codes for above groups of organisms may be modified by a decision of the above bodies.

7.4.4. Names of taxa (the rank of the genus and above)

The family names consist of one term only and called uninominal names. They are plural nouns or adjectives used as nouns. They are written with a capital initial letter. E.g.

Asteraceae, Lamiaceae. Names of the genera are uninomial and singular nouns. They are written with capital initial letter. E.g. *Hagenia*, *Datura*, *Withania* and etc. Names of the species consist of two terms, and called binomial, binominal or binary names. It contains the genus name in upper case followed by a second term which is peculiar to the species in lower case. The second term may be adjective or a noun, which is known as specific epithet.

7.5 Operative Principles of Nomenclature

The nomenclature code has set certain provisions, called Operative Principles of Nomenclature. These provisions are publication, typification and priority.

Publication

Publication is the means by which scientific names enter to the biological nomenclature system. The two basic conditions must be fulfilled before a properly formulated scientific name can have any legal status in biological nomenclature. Primarily the name must be published in works that are printed in permanent and made available to the interested public. Secondly, a name must be accompanied by a written matter or a reference to such description.

Typification

Type is the process of designating a nomenclatural type, or means by which types are allocated to taxa. A 'type' is an element on which the description associated with the original publication of a name was based. The 'type' of names of taxa above the Genus and below and including the Family is a Genus. The 'type' of the names of taxa above Species and below and including the Genus is a species; and the names of taxa below and including species is a specimen or sometimes a description or an illustration of a specimen. In nomenclature, there are different kinds of "Types". Some of these are:

- **Holotype:** It is the sole element used or designated by the author of a name as a type.
- **Isotype:** The duplicates of a holotype.
- **Syntype**: Is any one of two or more elements used by the author of a name who did not designate a holotype.
- **Lectotype:** Is an element selected subsequently from amongst syntypes to serve as a 'type'.

- **Neotype:** It is an element selected to serve as a nomenclatural type when through loss or destruction of the above "Types". Dear students please read about other kinds of "Types".

7.4.5.3. Priority

The principle of priority requires when two or more names apply to the same taxon. In this case, the name is given generally based up on by the oldest one, which is validly published name. However, one of the limitations of priority is the starting-point date, which is the date of publication of a work prior to which no name is considered to have been made available for zoological code and validly published names for botanical code.

There are certain names that are not considered in the code. For example, homonyms -names spelt in an identical manner but based on different ‘types’ of the organism, superfluous names-names that include the ‘type’ of another name when published, and tautonyms-name of a species in which the second term exactly repeats the generic names have no any legal status in the code. However, tautonyms are allowed in zoological code.

In nomenclature, when two or more names are applied the same taxon, it is known as synonyms. There are two kinds of synonyms; nomenclatural and taxonomic synonyms. The first names are based on the same ‘type’ of the organism and called obligateor homotypic synonyms. Taxonomic synonyms are based on different ‘type’ of an organism, and called heterotypic synonyms.

Authorities and Their Citations

The scientific names of organisms are often written followed by one or more personal names or the author name, who first published the name in the way that satisfies the criteria of valid publication or available names. Sometimes it is abbreviated. E.g. *Rumex abyssinicus* Jacq., *Plantago lanceolata* L. Sometimes, double citations are required. A double citation indicates there has been a change in taxonomic position or rank. For example, when a taxon below the rank of genus is transferred to another taxon, but also when a genus or taxon of lower rank is altered in rank but retains its original epithet. E.g. *Carissaedulis* Vahl.Later Linnaeus decided to place the specific epithet "*spinarum",* and written as *Carissa spinarum*(Vahl.) L.

Unit 8

Ecology and Conservation of Natural Resources (3 Hrs)

Dear student, this chapter deals with definition of ecology, basic concepts of ecology, aquatic and terrestrial ecosystems, energy flow through ecosystems and nutrient recycling. It also introduces students about conservation of natural resources, principles of conservation and environmental pollution and public health.

Learning objectives of the chapter

At the end of this chapter, the students will be able to:

- Define ecology briefly
- Describe types of ecosystems
- Describe the various terrestrial ecosystems
- Describe the various aquatic ecosystems
- Discuss primary and secondary productivity in the ecosystem
- Show trophic structures and energy flow in the ecosystems
- Explain the natural processes involved in nutrient cycling
- Sketch the diagrams of water, carbon, nitrogen and phosphorus cycles
- Describe the principles of conservation
- Illustrate the environmental pollution, causes and effects on human health.

8.1 Definition of ecological terms and Basic concepts of Ecology

Self-test

1. What is ecology? Why we study Ecology?
2. Do you know some of the ecological terms? List down.

Definition of Ecology

The word ‘Ecology’ was coined from Greek word 'oikos' meaning 'house' or 'a place to live' and 'logos' meaning study. Ecology is the study of the households of the planet earth. Living things depend on each other and on the non-living components of the environment for survival. Based on this, it is possible to say ecology is the study of the relationship of living organisms among themselves and with the non-living components of the environment. Different Authors defined ecology differently. Some of them are:

- ✓ Ecology is the scientific study of the interactions between organisms and their environments
- ✓ The study of the relationships, distribution, and abundance of organisms, or groups of organisms, in an environment

Ecology deals with relationships between organisms and their physical environments; between organisms of the same species; between organisms of different species; and between organisms and the fluxes of matter and energy through biological systems (Environment includes not only the physical but also the biological conditions under which an organism lives).

Ecologists study these interactions in order to understand the abundance and diversity of life within Earth's ecosystems. In other words, why there are so many plants and animals, and why there are so many different types of plants and animals? To answer these questions, they may use field measurements, such as counting and observing the behavior of species in their habitats; laboratory experiments that analyze processes such as predation rates in controlled settings; or field experiments, such as testing how plants grow in their natural setting but with different levels of light, water, and other inputs. Applied ecology uses information about these relationships to address issues such as developing effective vaccination strategies, managing fisheries without over-harvesting, designing land and marine conservation reserves for threatened species, and modeling how natural ecosystems may respond to global climate change.

Change is a constant process in ecosystems, driven by natural forces that include climate shifts, species movement, and ecological succession. By learning how ecosystems function, we can improve our ability to predict how they will respond to changes in the environment. But since living organisms in ecosystems are connected in complex relationships, it is not always easy to anticipate how a step such as introducing a new species will affect the rest of an ecosystem.

Ecological terminologies and their definitions

Students are expected to understand the meaning of the following terminologies since they are important throughout the course to grasp its concept.

1. **Abiotic:** all non-living components in the biosphere, e.g., air, water, soil, climate.
2. **Autotrophic:** when an organism is able to produce its own food using abiotic components.
3. **Biotic:** all the living components in the biosphere: animals, plants, micro-organisms**,** etc.
4. **Biosphere:** it is the global sum of all ecosystems, and is the zone where all living organisms live on earth.
5. **Biome:** the biosphere is divided into millions of biomes, based on the specific climate of each region, where the climate determines the unique plant and animal species that live and are adapted to survive in a region.
6. **Carnivores:** animals that eat only meat. They are generally predators, like lions, cheetahs etc., in a specific environment.
7. **Ecosystem**: the combined physical and biological components of a specific habitat where animals and plants are interdependent on each other for survival.
8. **Herbivores:** animals that only eat plants, e.g., buck, cows, goats, sheep, rabbits etc.
9. **Heterotrophic:** when an organism is unable to produce its own food, and must eat other organisms
10. **Omnivores:** animals that eat both plant and animal matter, e.g., humans, pigs, baboons.

11. **Saprophytic organisms:** organisms that live on dead organic matter because they are able to decompose (break down) dead plant and animal matter.
12. **Scavengers:** animals that eat what is left over by predators. Examples are hyenas, crayfish and vultures.
13. **Photosynthesis:** a process where plants use sunlight energy, water and CO_2 from the air, to produce organic compounds like glucose and inorganic compounds like O_2.
14. **Vegetation:** the plant life that is found in a biome.

8.2 Branches of ecology

Self-test:

1. What are the branches of ecology?
2. What criteria are employed for this classification?

- Ecology can be divided depending on the following concepts:-
  - ✓ Hierarchical organization –according to level of organization
  - ✓ Taxonomic –according to organisms studied
  - ✓ Time/Place -According to time/place

Many other ways to subdivide ecology:

A) Hierarchic: organism, population, community, ecosystem, biosphere

B) Taxonomic: plant ecology, animal ecology, microbial ecology, avian ecology, etc.

C) Time/Place: marine ecology, tropical ecology, freshwater ecology

Hierarchical structure of ecological systems

Organism: fundamental unit of ecology. No smaller unit in biology has an independent life in the environment.

Population: A group of organisms consisting of a number of different populations that live in defined area and interact with each other.

Community: A group of organisms consisting of a number of different species that live in an area and interact with each other

Ecosystem: a biological community plus all of the abiotic factors influencing that community.

Biome: A distinct ecological community of plants and animals living together in a particular climate.

Biosphere: the aggregation of all ecosystems (the sum of all of the organisms of the earth and their environment). Biome is the living zone of the planet.

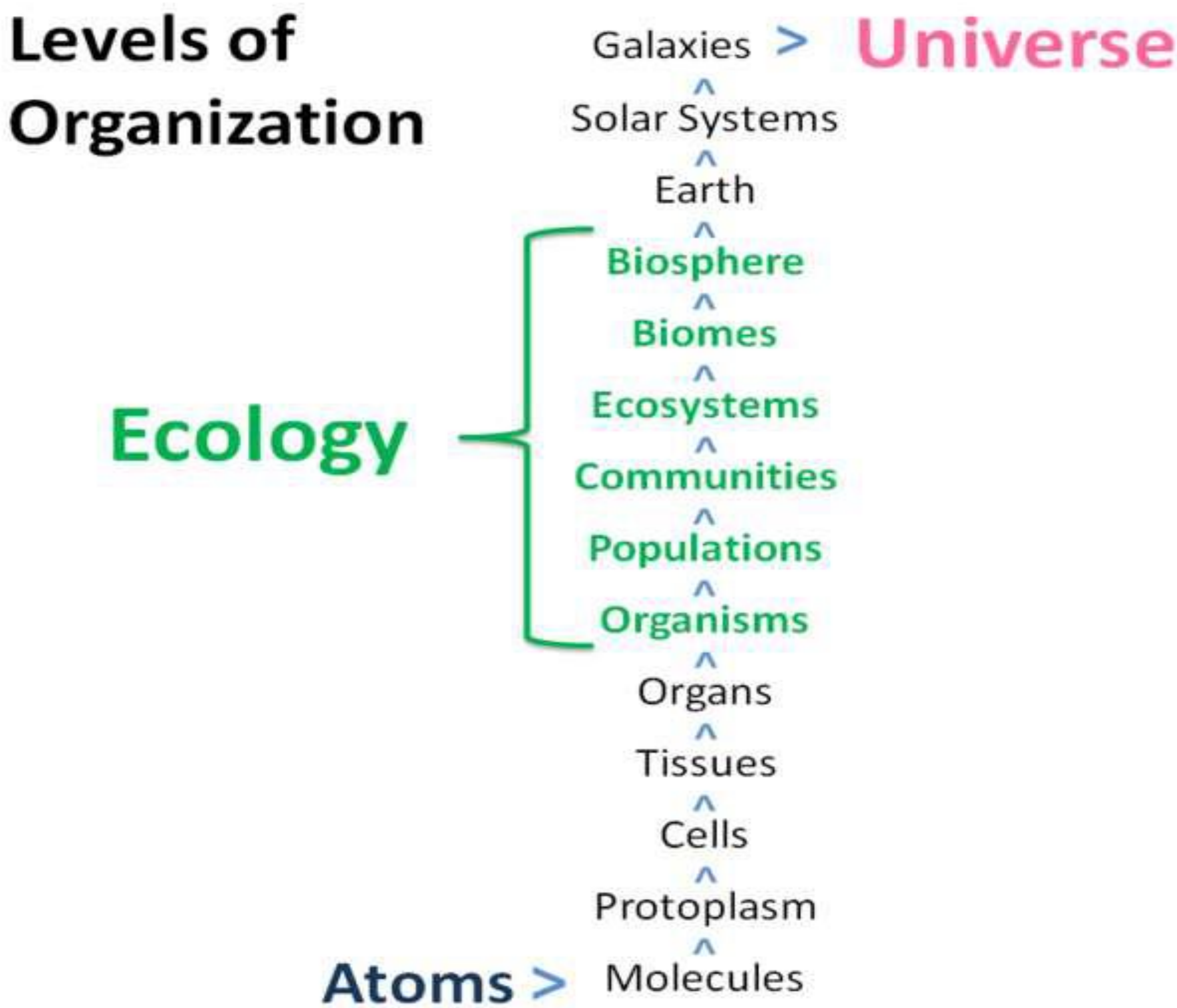


Fig: 8.1. Hierarchical structure of ecological systems

Some examples of the above ecological branches are given below:

- **Population ecology (or Autecology**)
    - It is concerned with population growth including birth rates and death rates, fluctuation, spread and interactions (scientific study of relationships between organisms of the same species).

- **Community ecology (or Synecology)**
    - Community ecology is the scientific study of relationships between organisms of different species.
- **Ecosystems ecology**, having to do with the structure and function of the entire suite of microbes, plants, and animals, and their abiotic environment, and how the parts interact to generate the whole. This branch of ecology often focuses on the energy and nutrient flows of ecosystems, and when this approach is combined with computer analysis and simulation it is often called systems ecology.
- **Evolutionary ecology**, which may operate at any of these levels but most commonly at the physiological or population level, is a rich and dynamic area of ecology focusing on attempting to understand how natural selection developed the structure and function of the organisms and ecosystems at any of these levels.
- **Conservation ecology: -**it deals with methods of proper management of natural resources such as land, water, forests, sea, mines, etc., for the benefit of human beings.

***Activity**:*

1. *What are the practical applications of ecology in your daily life?*

8.3 Aquatic and terrestrial ecosystems

A natural ecosystem is an assemblage of plants and animals which functions as a unit and is capable of maintaining its identity such as forest, grassland, an estuary; human intervention is an example of a natural ecosystem. A natural ecosystem is totally dependent on solar energy. There are two main categories of ecosystems.

A) Aquatic ecosystem

An aquatic ecosystem is an ecosystem in a body of water. Communities of organisms that are dependent on each other and on their environment live in aquatic ecosystems. The two main types of aquatic ecosystems are:

1. Marine ecosystems
2. Freshwater ecosystems

1. Marine ecosystems cover approximately 71% of the earth's surface and contain approximately 97% of the planet's water. They are distinguished from freshwater ecosystems by the presence of dissolved compounds, especially salts, in the water. Approximately 85% of the dissolved materials in seawater are sodium and chlorine. Organisms found in marine ecosystems include brown algae, dinoflagellates, corals, cephalopods, echinoderms, sharks…etc. Fishes caught in marine ecosystems are the biggest source of commercial foods obtained from wild populations.

2. Freshwater ecosystems

- Freshwater ecosystems (occupy only about 2% of earth's surface). Example
    - i. Rivers and streams: flowing-water ecosystems
    - ii. Lakes and ponds: standing-water ecosystems
- A large lake has three zones:

a) The littoral zone is a shallow-water area along the shore of a lake or pond where light reaches the bottom; it is the most productive section of the lake.

b) The limnetic zone is the open water beyond the littoral zone; it extends down as far as sunlight penetrates to permit photosynthesis.

c) The profundal zone is beneath the limnetic zone; light does not penetrate effectively to this depth (no plants or algae found here). Thermal stratification and turnover in temperate lakes:

Thermal stratification is the marked layering of large temperate lakes caused by how far light penetrates it, causing temperature to change sharply with depth.

Falling temperatures in fall, and rising temperatures in spring cause turnover, a mixing of the layers of lake water.

3. Marshes and swamps: freshwater wetlands

- Grass like plants dominate in marshes, while woody trees and/or shrubs dominate in swamps.
- Wetlands are valued wildlife habitats of migratory birds, beaver, otters, muskrats, and game fishes; they provide natural flood control and serve as groundwater recharging areas.

Estuaries: are where fresh and salt water meet.

i. Estuaries are among the most fertile ecosystems in the world
ii. Temperate estuaries usually contain salt marshes which are important in preventing flood damage during storm surges
iii. Mangrove forests are the tropical equivalent of salt marshes; they cover nearly 70% of tropical coastlines.
    - Mangroves are breeding ground and nurseries for several commercially important fishes, shellfish, and birds.
    - They also help prevent coastal erosion and provide a barrier against the ocean during storms/hurricanes.

Activity:

Explain the two main types of aquatic ecosystem

B. Terrestrial ecosystems

Self test

1. Write some of the terrestrial ecosystems with their characteristic features

Terrestrial ecosystems include:

(a) Forests
(b) Grasslands,
(c) Deserts and (d) tundra

(a) **Forests**: are large areas supporting rich growth of trees. Depending on the climate and type of trees they are generally grouped into:

i. Tropical rain forests
ii. Temperate deciduous forests
iii. Boreal or north coniferous forests include

i. Tropical rain forest

Distribution: These are found in the high rain fall areas on either side of the equator. Such forests are found in the western coast of India, scattered in south East Asia, some parts of Africa and South America.

Flora and fauna: Tropical rainforests occur in areas by having high temperature and high humidity and receives above 200 cm of rainfall per year. Soil is rich in humus. These forests have a very rich biodiversity e.g. Brazilian tropical rain forests have more than 300 species of trees in an area of 200 square kilometer. Trees are tall growing up to 50 to 60 m. These forests also support epiphytes, like vines, creepers, woody creepers and orchid etc. These forests are rich in tree dwelling animals such as monkeys, flying squirrels, snails, centipedes, millipedes, and many insect species are common on the forest floor.

ii. Temperate deciduous forests

- **Distribution:** They occur mostly in the Northwest, Central and Eastern Europe, Eastern North America, North China, Korea, Japan, far Eastern Russia and Australia. Trees of deciduous forests shed their leaves in autumn and new foliage grow in spring.
- **Climate:** These forests occur in the areas of moderate climatic conditions such as temperature ranging but 10 to 20^0C with a 6 month long winter and an annual rainfall between 75 to 150 cm. They have its brown soils which are rich in nutrients.
- **Flora and fauna:** Common trees are oak, beach, heath, chest nut, birch, pine. These forests also show stratification and have a under story of saplings shrubs and tall herbs. Prominent grazers include deer, bison and rodents. Rodents play a very important role in these forests. They feed on seeds, fruits and tree leaves. Black bear, raccoons, wild cat, wolves, fox and skunks are the omnivores found in these forests. Hibernation or winter sleep during winter is a common feature of animals found in these forests. Invertebrate fauna comprises green flies, aphids, certain moths and butterflies.

iii. **Boreal or north coniferous forests:**

- **Distribution:** Coniferous forests are also known as ‘Taiga’. They extend as a continuous belt across North America and north Eurasia below the arctic tundra. There is no counterpart of these forests in southern hemisphere as there is no land at this latitude. Climate is cold with long, harsh winter, with mean annual temperature below 0^0C. The soils are acidic and poor in nutrients.
- **Flora and fauna:** Coniferous forests are characterized by evergreen, drought resistant and woody. Conifers (gymnosprerms) e.g. spruce, fir and pine trees which bear naked seeds in cones. The animals found in these forests, are red squirrel, deer, goat, mule, moose etc. The carnivores which feed upon them are timber wolves, lynxes, and bear. Some common birds are crossbill, thrushes, warblers, flycatchers, robin and sparrow.

Grasslands

- **Distribution:** Grasslands are areas dominated by grasses. They occupy about 20% of the land on the earth surface. Grasslands occur in both in tropical and temperate regions where rainfall is not enough to support the growth of trees. Grasslands are known by various names in different parts of the world. For example:

Table 8.1.

Place	**Name of the grassland**
North America	Prairies
Eurasia (Europe and Asia)	Steppes
Africa	Savanna
South	America Pampas
India	Grassland, Savanna

Grasslands are found in areas having well defined hot and dry, warm and rainy seasons. Tropical grasslands are commonly called Savannas. They occur in eastern

Africa, South America, Australia and India. Savannas form a complex ecosystem with scattered medium size trees in grass lands.

• **Flora and fauna:** Grasses are the dominating plants with scattered drought resistant thorny trees in the tropical grasslands. Badgers, fox, ass, zebra, antelope are found grazing on grasslands which support the dairy and leather industries. Grasslands also support large population of rodents, reptiles and insects.

Deserts

• **Distribution:** Deserts are hot and low rain areas suffering from water shortage and high wind velocity. They show extremes of temperature. Globally deserts occupy about 1/7th of the earth's surface.

• **Flora and fauna:** Cacti, Acacia, Euphorbia and prickly pears are some of the common desert plants. Desert animals include shrew, fox, wood rats, rabbits, camels and goat are common mammals in desert. Other prominent desert animals are, reptiles, and burrowing rodents insects.

•**Adaptations**:

Desert plants and animals adapt both hot and dry conditions.

(i) These plants conserve water by the following methods:

- ✓ They are mostly shrubs.
- ✓ Leaves absent or reduced in size.
- ✓ Leaves and stem are succulent and water storing.
- ✓ In some plants even the stem contains chlorophyll for photosynthesis.
- ✓ Root system well developed spread over large area.

(ii) The animals are physiologically and behaviorally adapted to desert conditions.

- ✓ They are fast runners.
- ✓ They are nocturnal in habit to avoid the sun's heat during day time.
- ✓ They conserve water by excreting concentrated urine.
- ✓ Animals and birds usually have long legs to keep the body away from the hot ground.
- ✓ Lizards are mostly insectivorous and can live without drinking water for several days.

- ✓ Herbivorous animals get sufficient water from the seeds which they eat. Camel is known as the ship of the desert as it can travel long distances without drinking water for several days.

Tundra: The word tundra means a "barren land" since they are found in those regions of the world where environmental conditions are very severe.

There are two types of tundra: arctic and alpine.

• **Distribution:** Arctic tundra extends as a continuous belt below the polar ice cap and above the tree line in the northern hemisphere. It occupies the northern fringe of Canada, Alaska, European Russia, Siberia and island group of Arctic Ocean. On the South Pole Antarctica **tundra** in the South Pole is very small since most of it is covered by ocean. Alpine tundra occurs at high mountains above the tree line. Since mountains are found at all latitudes therefore alpine tundra shows day and night temperature variations.

• **Flora and fauna:** Typical vegetation of arctic tundra is cotton grass, sedges, dwarf heath, willows, birches and lichens. Animals of tundra are reindeer, musk ox, arctic hare, caribous, lemmings and squirrel. Most of them have long life e.g. *Salix arctica* that is arctic willow has a life span of 150 to 300 years. They are protected from chill by the presence of thick cuticle and epidermal hair. Mammals of the tundra region have large body size and small tail and ear to avoid the loss of heat from the surface. The body is covered with fur for insulation. Insects have short life cycles which are completed during favorable period of the year.

Activities:

1. What are deciduous trees?
2. Explain two common characteristics of the desert.
3. How do the animals and plants of deserts adapted to heat and drought?
4. Where prairies and steppes are found?

8.4 Energy flow through ecosystems

The transfer of energy from the source in plants through a series of organisms by eating and being eaten constitutes food chains. At each transfer, a large proportion of energy is lost in the form of heat. These food chains are not isolated sequences, but are interconnected with each other. This interlocking pattern is known as the food web. Each step of the food web is called a trophic level. Hence green plants occupy the first level, herbivores the second level, carnivores the third level and secondary carnivores the fourth level. These trophic levels together form the ecological pyramid.

8.4.1 The food chains

The transfer of food - energy from plants to animals and then to other animals by successive stage of feeding is called a food chain**.** The cyclic interdependence of one trophic level over the others forms a food chain. A food chain is also defined as "the sequence of organisms that are related to each other for their source of food." In an ecosystem, energy is transferred through a series of organisms, each feeding on the preceding organisms and providing raw materials and energy for the next organisms. Each stage of the food chain is known as trophic level. The first trophic level is occupied by the autotrophic organisms, so they are called producers.

The organisms of the second trophic level are called primary consumers or herbivores. Twenty percent (20%) to thirty percent (30%) of net primary production is consumed by the herbivores. The organisms of the third trophic level are called secondary consumers or primary carnivores. The organisms of the fourth trophic level are called tertiary consumers or secondary carnivores. The final carnivore of a food chain is not eaten by other animals, so it is known as climax carnivore.

In nature, basically two types of food chains are recognized: They are grazing food chain and detritus food chain.

i) Grazing food chain: starts from the living green plants and goes to grazing herbivores and on to the carnivores. Ecosystems with such type of food chain are directly dependent on an influx of solar radiation. Thus, this type of food chain depends on autotrophic energy capture and the movement of this energy to herbivores. Most of the ecosystems in nature follow this type of food chain. These chains are very significant from energy standpoint.

The following are examples of grazing food chain:

1. Aquatic food chain: Phytoplanktons →zooplanktons→fish
2. Terrestrial food chain :Grasses→Rabbit→fox

ii) Detritus food chain

The organic wastes, exudates and dead matter derived from the grazing food chain are generally termed as detritus. The energy contained in this detritus is not lost to the ecosystem as a whole; rather it serves as the source of energy for a group of organisms (detritivores) that are separated from the grazing food chain. The detritus food chain represents an exceedingly important component in the energy flow of an ecosystem. Indeed in some ecosystems, considerably more energy flows through the detritus food chain than through the grazing food chain. In the detritus food chain the energy flow remains as a continuous passage rather than as a stepwise flow between discrete entities. The organisms of the detritus food chain are many and include algae, bacteria, slime molds, actinomycetes, fungi, protozoa, insects, mites, crustacea, centipedes, molluscs, rotifers, annelid worms, and nematodes.

Other feeding groups such as parasites and scavengers form supplementary food chains in the ecosystem. Parasitic food chains are highly complicated because of the life cycle. Some parasites are passed from one host to another by predatory in the food chains. External parasites (ectoparasites) may move from one host to another. Other parasites are transmitted by insects from one host to another through the blood stream or plant floods. Food chain also exists among parasites. For instances, fleas that parasitize mammals and birds are in turn parasitized by protozoan, leptosomes.

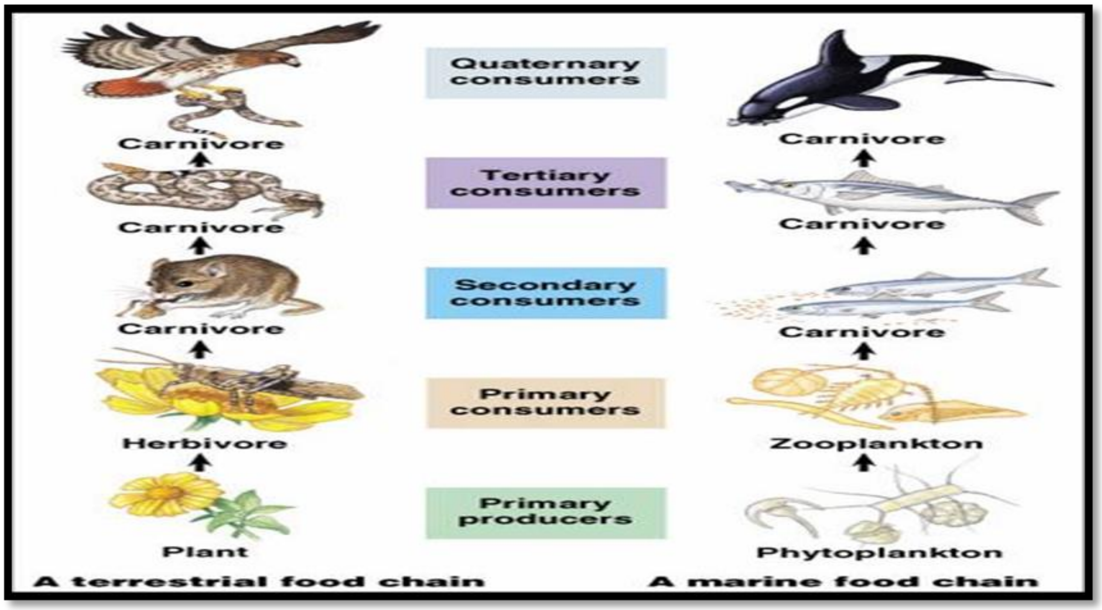


Fig: 8.2: Terrestrial and aquatic food chain

8.1.2.2 The food web

Self test

1. What does food web mean? How it is different from food chain?

In an ecosystem there are a very large number of interlinked chains and forms a food web. Stability of the ecosystem is maintained by food web. If the linkages in the chains that make up the web of life are disrupted due to human activities that lead to the extinction of species, the web will breaks down.

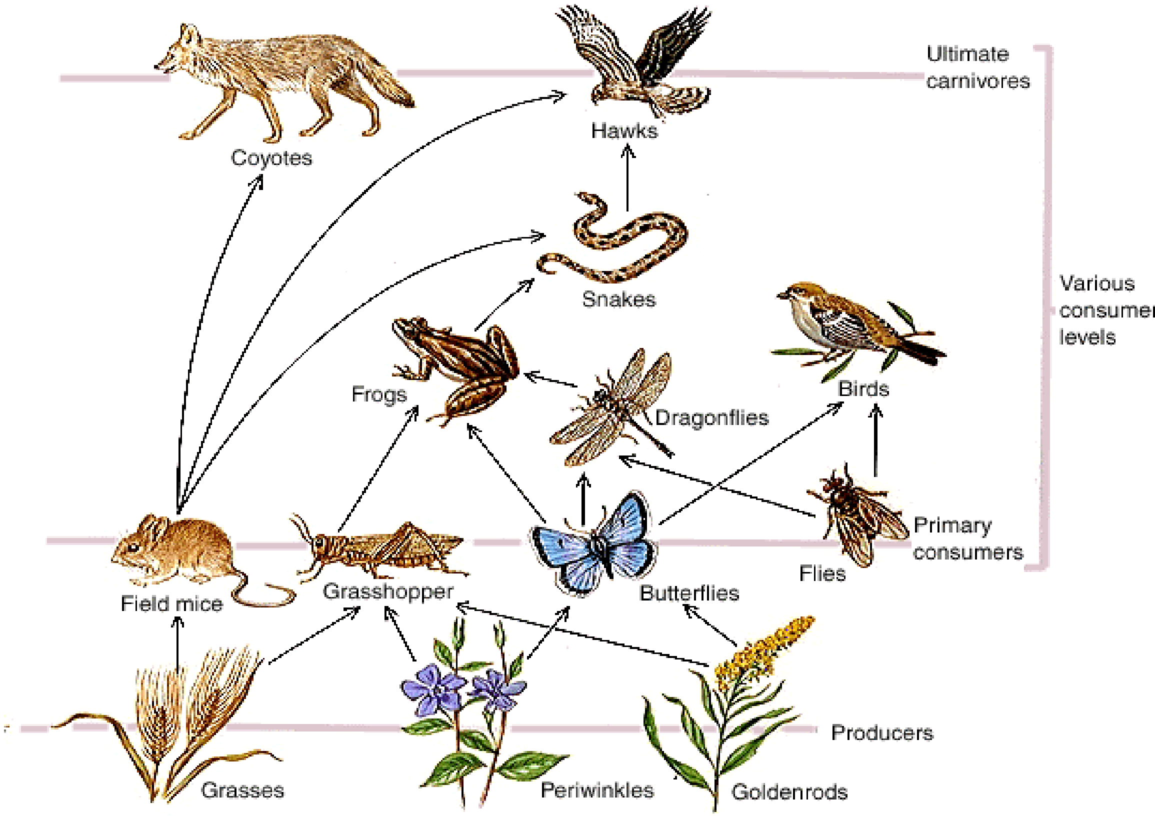


Fig: 8.3. Food web

8.1.2.3 Ecosystem productivity

Productivity in land ecosystems generally rises with temperature about 30^{o}C, after which it declines, and is positively correlated with moisture. On land primary productivity is highest in warm, wet zones in the tropics where tropical forest biomes are located. In contrast, desert scrub ecosystems have the lowest productivity because their climates are extremely hot and dry.

A. Primary production

The flow of energy through a terrestrial ecosystem starts with the harnessing of sunlight by green plants, a process that in itself demands the expenditure of energy. A plant gets its start by living on the food energy stored in the seed until it produces leaves. Energy accumulated by plants is called primary production, because it is the first and basic form of energy stored. Total energy assimilated by the plant is gross primary production. Plants, like all other organisms, must expend energy in production, maintenance, and reproduction. This energy is produced by the process of respiration which librates energy. Energy remaining after respiration and stored as organic matter is net primary production. Net primary production can be described by the following equation:

Net primary production (NPP) = gross primary production (GPP) - respiration by the autotroph (R). Production is expressed in kilocalories per square meter ($kcal/m^2$) and can also expressed in grams per square meter (g/m^2).

B. Secondary production

Net primary production is the energy available to the heterotrophic component of the ecosystem. The energy left over from maintenance and respiration goes into production, including both the growth of new tissues and the production of young. This net energy of production is called secondary production.

Activities:

1. How does energy flow occur from one organism to another?
2. How many trophic levels can an ecosystem support?
3. Why do primary consumers get more energy than secondary consumers?
4. How much energy does a consumer obtain from producer?

8.1.3 Ecological pyramid

Ecological pyramid is the graphic representation of the number, biomass and energy of the successive trophic levels of an ecosystem. The concept of ecological pyramid was first described by Charles Elton. Ecological pyramids represent the trophic structure (feeding relationships) and trophic function (efficiency of energy transfer through biotic components) of an ecosystem.

Types of ecological pyramid

I) Pyramid of number depicts the number of individual organisms at different trophic levels of food chain.

II) Pyramid of biomass depicts the amount of biomass at different trophic levels of food chain or the total weight of living matter per unit area present in the ecosystem.

III) Pyramid of energy depicts the amount of energy at different trophic levels of food chain. It shows how energy moves throughout an ecosystem. As you move up the pyramid levels, approximately 90% of the food's original energy is lost from level to level because animals must use their own energy to consume and digest food. The consumers at the top of the pyramid do not have as much energy available to them because their food, another animal, is simply not very good at converting the food it eats into energy in its body.

Ecological pyramids are always upright; i. e. the apex is pointed upwards. In some ecosystems the number and biomass of producers are less and those of consumers are more. So the apex is directed down wards. This type of pyramid is called inverted pyramid**.** Inverted pyramid of numbers is found in parasitic food chain. Inverted pyramid of biomass occur in pond and lake ecosystems. However, the pyramid of energy is always upright (never inverted).

Fig: 8.4. Pyramid of Energy

Activity. Why the pyramid of numbers is inverted in parasitic food chain?

8.5 Cycling of Materials (Nutrients)

Every ecosystem has several interrelated mechanisms that affect human life. These are the water cycle, the carbon cycle, the oxygen cycle, the nitrogen cycle and the energy cycle. While every ecosystem is controlled by these cycles, in each ecosystem its abiotic and biotic features are distinct from each other.

All the functions of the ecosystem are in some way related to the growth and regeneration of its plant and animal species. These linked processes can be depicted as the various cycles. These processes depend on energy from sunlight. During photosynthesis, carbon dioxide is taken up by plants and oxygen is released. Animals depend on this oxygen for their respiration. The water cycle depends on the rainfall, which is necessary for plants and animals to live. The energy cycle recycles nutrients into the soil on which plant life grows. Our own lives are closely linked to the proper functioning of these cycles of life. If human activities go on altering them, humanity cannot survive on our earth.

8.2.1 The Water Cycle

When it rains, the water runs along the ground and flows into rivers or falls directly into the sea, and part of the rainwater falls on land percolates into the ground. This is stored underground throughout the rest of the year. Water is drawn up from the ground by plants along with the nutrients from the soil. Then, water is transpired from the leaves as water vapour and returned to the atmosphere. As it is lighter than air, the water vapor rises and forms clouds. Winds blow the clouds for long distances and when the clouds rise higher, the vapour condenses and changes into droplets, which fall on the land as rain. Though this is an endless cycle on which life depends, man’s activities are making drastic changes in the atmosphere through pollution which is altering rainfall patterns.

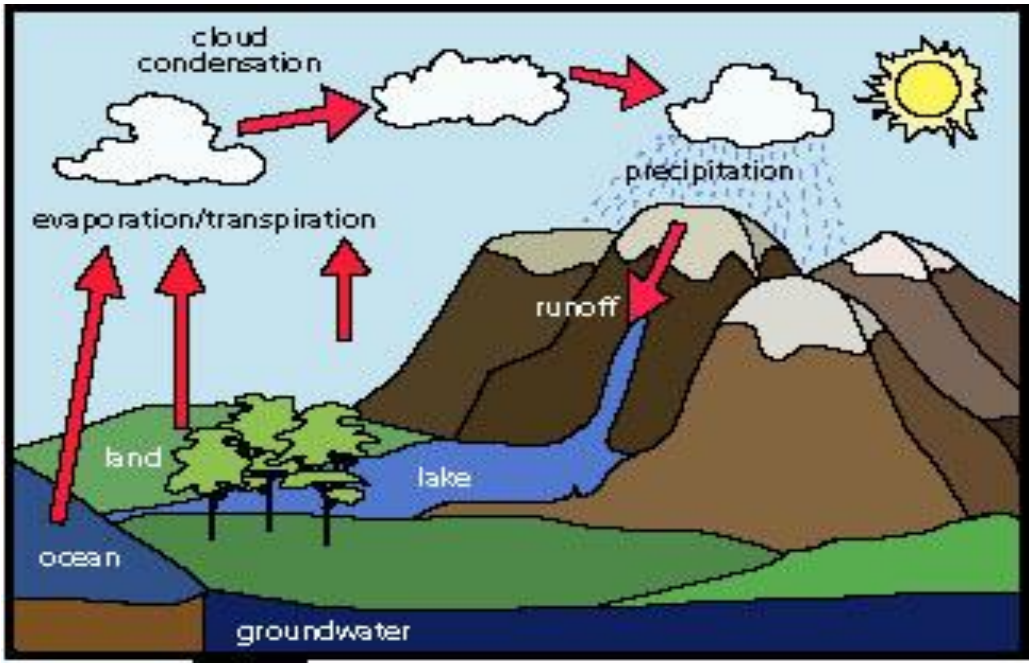


Fig: 8.5. Water cycle

8.2.2 The Carbon cycle

The carbon, which occurs in organic compounds, is included in both the abiotic and biotic parts of the ecosystem. Carbon is a building block of both plant and animal tissues. In the atmosphere, carbon occurs as carbon dioxide (CO_2). In the presence of sunlight, plants take up carbon dioxide from the atmosphere through their leaves. The plants combine carbon dioxide with water, which is absorbed by their roots from the soil. In the presence of sunlight they are able to form carbohydrates that contain carbon. This process is known as photosynthesis. Plants use this complex mechanism for their growth and development. In this process, plants release oxygen into the atmosphere on which animals depend for their respiration. Plants therefore help in regulating and monitoring the percentage of oxygen and carbon dioxide in the earth's atmosphere. All of mankind thus, depends on the oxygen generated through this cycle. It also keeps the CO_2 at acceptable levels.

Herbivorous animals feed on plant material, which is used by them for energy and for their growth. Both plants and animals release carbon dioxide during respiration. They also return fixed carbon to the soil in the waste they excrete. When plants and animals die they return their carbon to the soil. These processes complete the carbon cycle.

8.2.3 Nitrogen cycle

- 78% of the air is nitrogen
- Plants use nitrogen in their cellular processes
- Nitrogen is present in our DNA and RNA and in amino acids (proteins).
- The food chain largely moves nitrogen around.

Nitrogen Fixation

Nitrogen fixation is the conversion of atmospheric nitrogen (N_2) into reactive compounds such as ammonia (NH_3) and nitrate (NO_3^-). The breaking of the bonds between the nitrogen atoms requires a great deal of energy and occurs naturally in two primary ways:

i. Abiotic Fixation: Nitrate is the result of high energy fixation in the atmosphere from lightning and cosmic radiation. In this process, N_2 is combined with oxygen to form nitrogen oxides such as NO and NO_2, which are carried to the earth's surface in rainfall as nitric acid (HNO_3). This high energy fixation accounts for approximately 10% of the nitrate entering the nitrogen cycle.

ii. **Biological fixation:** It is accomplished by a series of soil micro-organisms such as aerobic and anaerobic bacteria. Often, symbiotic bacteria such as *Rhizobium* are found in the roots of legumes and provide a direct source of ammonia to the plants. In root nodules of these legumes, the bacteria split molecular nitrogen into two free nitrogen atoms, which combine with hydrogen to form ammonia (NH_3). The following plants are common examples of legumes: clover, alfalfa, soy beans, and chick peas. The breakdown of these legumes by bacteria during ammonification actually returns excess nitrogen not utilized by the plant to the surrounding soil. Therefore, to promote sustainable soil fertility, it is beneficial to use these agricultural crops in rotation with other plants, such as corn, that are more profitable but deplete the available nitrogen in the soil some free-living aerobic bacteria, such as *Azotobacter*, and anaerobic bacteria, like *Clostridium*, freely fix nitrogen in the soil and in aquatic environments. Some members of the photosynthetic cyanobacteria phylum fix nitrogen in aquatic environments as well.

Nitrification – conversion of ammonia in soil to nitrite ions and finally to nitrate ions that are easily used by plants (aerobic bacteria).

Assimilation

Nitrates are the form of nitrogen most commonly assimilated by plants through root hairs. Since heterotrophic organisms cannot readily absorb nitrogen as plants do, they rely on acquiring nitrogen-based compounds through the food they eat. Since plants are the base of the food chain, the nitrogen-based compounds they have assimilated into their tissue will continue to pass from one organism to another (through consumption) as matter and energy transfers through the ecosystem's food web.

Ammonification

In ammonification, a host of decomposing microorganisms, such as bacteria and fungi, break down nitrogenous wastes and organic matter found in animal waste and dead plants and animals and convert it to inorganic ammonia (NH_3) for absorption by plants as ammonium ions. Therefore, decomposition rates affect the level of nutrients available to primary producers.

Denitrification

It is the process by which nitrates are reduced to gaseous nitrogen (N_2) and lost to the atmosphere. This process occurs by facultative anaerobes in anaerobic environments. Farmers with waterlogged fields and soils that have high clay content are especially vulnerable to nitrogen losses due to denitrification. In short it is conversion of ammonia and ammonium ions to nitrate and nitrite ions and then back into nitrogen gas and nitrous oxide gas.

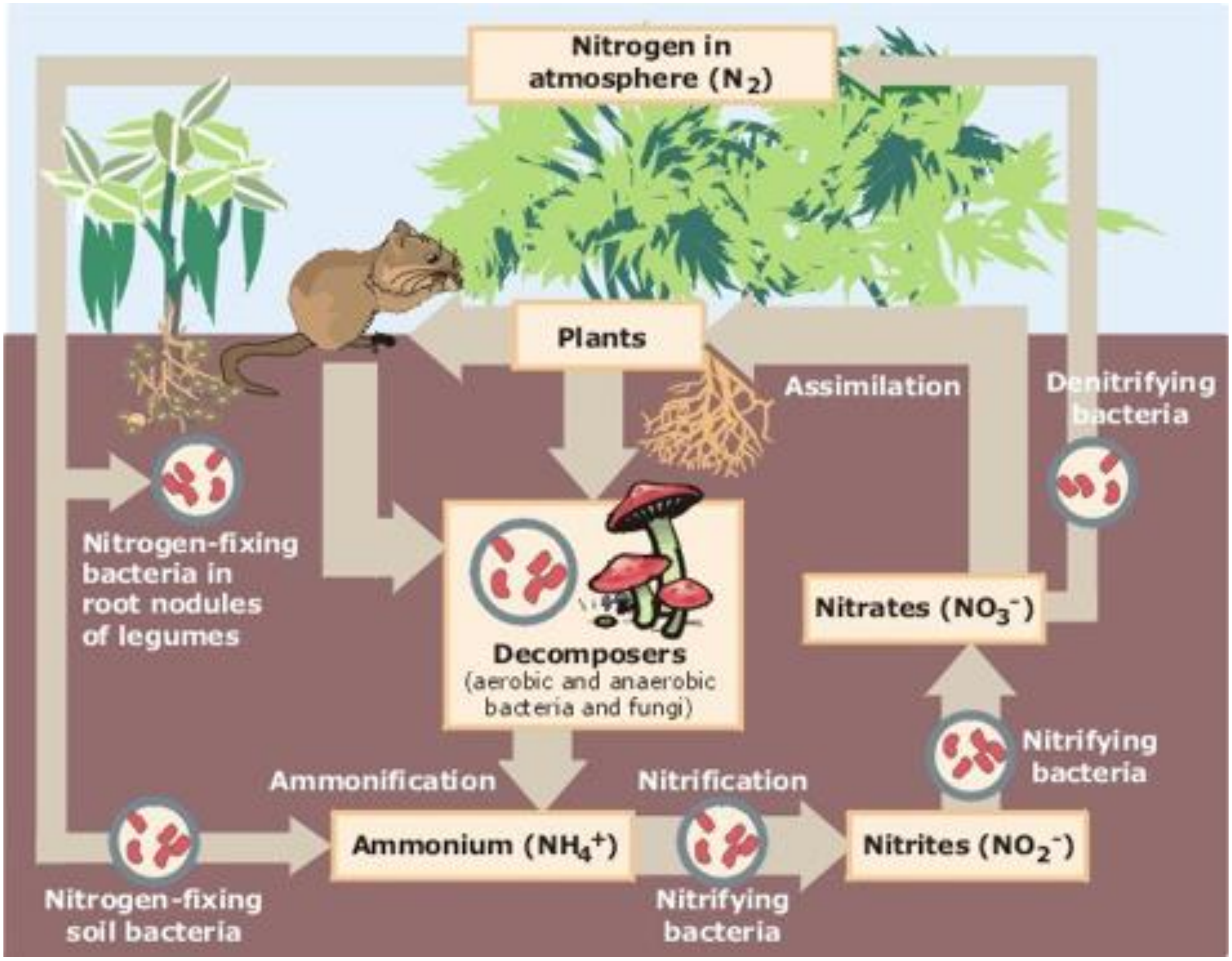


Fig: 8.6 Nitrogen cycle

Activity:

Describe the following terms briefly and mention some microorganisms involved in each process.

a) Nitrification b) Ammonification c) Denitrification

8.2.4 The Oxygen Cycle

Oxygen is taken up by plants and animals from the air during respiration. The plants return oxygen to the atmosphere during photosynthesis. This links the oxygen cycle to the carbon cycle. Deforestation is likely to gradually reduce the oxygen levels in our atmosphere. Thus, plant life plays an important role in our lives which we frequently do not appreciate. This is an important reason to participate in forestation programs.

8.2.5 Phosphorus cycle

The phosphorus cycle, is the circulation of phosphorous among the rocks, soils, water, and plants and animals of the earth. The phosphorous cycle is the simplest of the cycles that we will examine. For our purposes, phosphorous has only one form, phosphate **(PO_4^{-3})**, which is a phosphorous atom with four oxygen atoms. This heavy molecule never makes its way into the atmosphere; it is always part of an organism, dissolved in water, or in the form of rock. When rock with phosphate is exposed to water (especially water with a little acid in it), the rock is weathered out and goes into solution. Autotrophs take this phosphorous up and use it in a variety of ways. It is an important constituent of cell membranes, DNA, RNA, and, of course ATP. Heterotrophs obtain their phosphorous from the plants they eat, although one type of heterotroph, the fungi, excel at taking up phosphorous and may form mutualistic symbiotic relationships with plant roots. These relationships are called *Mycorrhizae*; the plant gets phosphate from the fungus and gives the fungus sugars in return. Animals, by the way, may also use phosphorous as a component of bones, teeth and shells. When animals or plants die (or when animals defecate), the phosphate may be returned to the soil or water by the decomposers. There, it can be taken up by another plant and used again. This cycle will occur over and over until at last the phosphorous is lost at the bottom of the deepest parts of the ocean, where it becomes part of the sedimentary rocks forming there. Ultimately, phosphorous will be released if the rock is brought to the surface and weathered. Two types of animals play a unique role in the phosphorous cycle. Humans often mine rock rich in phosphorous. For instance, in Florida, which was once sea floor, there are extensive phosphate mines. The phosphate is then used as fertilizer. This mining of phosphate and use of the phosphate as fertilizer greatly accelerates the phosphorous cycle and may cause local overabundance of phosphorous, particularly in coastal regions, at the mouths of rivers, and anyplace where there is a lot of sewage released into the water (the phosphate placed on crops finds its way into our stomachs and from there to our toilets). Local abundance of phosphate can cause overgrowth of algae in the water; the algae can use up all the oxygen in the water and kill other aquatic life. This is called eutrophication. The other animals that play a unique role in the phosphorous cycle are marine birds. These birds take phosphorous containing fish out of the ocean and return to land, where they defecate. Their guano (droppings of birds) contains high levels of phosphorous and in this way marine birds return phosphorous from the ocean to the land. The guano is often mined and may form the basis of the economy in some areas.

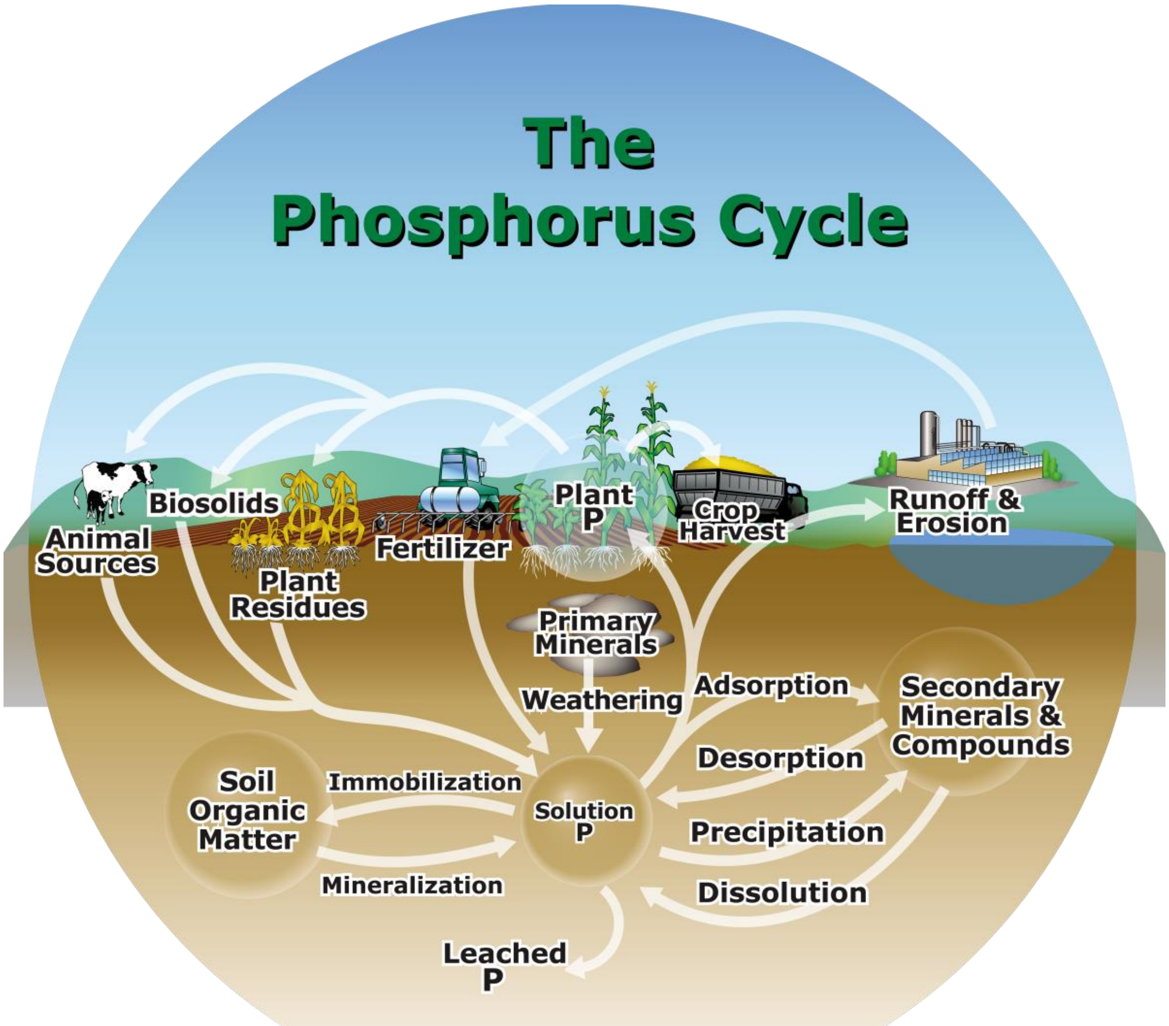


Fig: 8.7 Phosphorus cycle

8.6 Conservation of natural resources

8.6.1 Principles of conservation of natural resources

For standard and general criteria for conservation and sustainable use of natural resources, it should be developed at a local level and be adapted to local ecosystems, cultures, values and social and economic conditions. Where necessary, networks of protected areas, corridors and integrated management zones should be established first. Although the principles and strategies for sustainable resource management is not new concept, is now gaining the world's attention in response to the decline in the quality of the natural resource due to various natural and anthropogenic factors including modern agricultural expansion and urbanization.

Sustainable use of resources, especially the genetic resources for food and agriculture is vital for the next generation. Greater resource use-efficiency saves land, water and biodiversity, and enhances ecological services underpinning food production. In addition, improved resource-use efficiency can help to reduce pressure on ecosystems, which also subsequently lead to resource depletion and degradation. That is why direct action is needed to conserve, protect and enhance natural resources. Intensification practice of agricultural land over natural landscape often comes together with practices that include high use of inputs, in particular water, fertilizers, and pesticides is unwise use of resources. These in turn, when not properly used, deplete soils, pollute water, and destroy biodiversity. World's tropical forests remove from the atmosphere 4.8 billion tones of CO_2 a year, or about 18 percent of annual emissions from burning fossil fuels. Reforestation and reducing the rate of deforestation will not only mitigate impact of climate change. It should also contribute to sustainability through soil formation, water purification, biodiversity and pollination mechanisms.

According to convention on biodiversity, conservation of biodiversity, forests, fragile ecosystems and other natural resources are the major areas of resource managements. The major strategies of natural resource management techniques are *in-situ* and *ex-situ* or both methods. One of among other things, principles of conserving the natural resource is reducing the destruction to biodiversity, which in turn brings about hunger and poverty.

Biodiversity conservation still plays a pivotal role in sustaining and strengthening nutrition. It enhances the resilience of people, communities and ecosystems, especially to climate change and market volatility. Natural disasters or extreme weather events, food safety emergencies, market volatility and civil strife impair the livelihoods of millions of people who depend on natural resources for their livelihoods and negatively impact sustainability of food and other benefits of natural resources.

All of these principles of conservation can be possible through decisions made under various government and public participations, revenue protection policies, an insurance scheme incentivizing to diversify and conserve natural resources, adopt alternative resource utilization strategies, and apply integrated resources management policies among various institutions and individuals. In addition, promoting responsible and effective governance mechanisms are also bet methods for resource management principles. Especially, this approach is preferred since it ensures accountability, equity, transparency and the rule of law. The underpinning processes must be participatory and involve all key stakeholders, men, women, public and private sectors and civil society. They need to be provided with an enabling institutional and policy environment that provides the right incentives that support the adoption of appropriate practices on the ground. Responsible and effective governance creates trust and encourages the community to take part in resource conservation.

8.7 Environmental pollution and public health

Developmental activities such as construction, transportation and manufacturing not only deplete the natural resources but also produce large amount of wastes that leads to pollution of air, water, soil, and oceans; global warming and acid rains. Untreated or improperly treated waste is a major cause of pollution of rivers and environmental degradation causing ill health and loss of crop productivity. In this lesson, you will study about the major causes of pollution, their effects on our environment and the various measures that can be taken to control such pollutions.

Self-test

1. *Define pollutant and pollution*
2. *What is the difference between sources and sinks?*

Learning Objectives

After completing this lesson, you will be able to:

- define the terms pollution and pollutants;
- list various kinds of pollution;
- describe types of pollution, sources, harmful effects on human health and control of air pollution, indoor air pollution, noise pollution;
- describe water pollution, its causes and control;
- describe thermal pollution;
- discuss about soil pollution, its causes and control;
- describe radiation pollution, sources and hazards.

Pollution and pollutants

Human activities directly or indirectly affect the environment adversely. A stone crusher adds a lot of suspended particulate matter and noise into the atmosphere. Automobiles emit from their tail pipes oxides of nitrogen, sulphur dioxide, carbon dioxide, carbon monoxide and a complex mixture of unburnt hydrocarbons and black soot which pollute the atmosphere. Domestic sewage and run off from agricultural fields, laden with pesticides and fertilizers, pollute water bodies. Effluents from tanneries contain many harmful chemicals and emit foul smell. These are only a few examples which show how human activities pollute the environment. Pollution may be defined as addition of undesirable material into the environment as a result of human activities. The agents which cause environmental pollution are called pollutants. Pollutants may be defined as a physical, chemical or biological substance unintentionally released into the environment which is directly or indirectly harmful to humans and other living organisms.

Types of pollution

Self-test

1. List types of pollution

2. What are the main sources of pollution?

Pollution may be of the following types:

- Air pollution
- Noise pollution
- Water pollution
- Soil pollution
- Thermal pollution
- Radiation pollution

Air pollution

Air pollution is recognized as one of the leading contributors to the global environmental burden of disease, even in countries with relatively low concentrations of air pollution. Air pollution is a result of industrial and certain domestic activity. An ever increasing use of fossil fuels in power plants, industries, transportation, mining, construction of buildings, stone quarries had led to air pollution. Air pollution may be defined as the presence of any solid, liquid or gaseous substance including noise and radioactive radiation in the atmosphere in such concentration that may be directly and indirectly injurious to humans or other living organisms, plants, property or interferes with the normal environmental processes. Air pollutants are of two types (1) suspended particulate matter, and (2) gaseous pollutants like carbon dioxide (CO_2), NO_x etc.

Table 8.3.1 Particulate air pollutants, their sources and effects

Pollutant	Sources	Effects
Suspended particulate matter/dust	Smoke from domestic, industrial and vehicular soot	Depends on specific composition, Reduces sunlight and visibility, increases corrosion, Pneumoconiosis, asthma, cancer, and other lung diseases.
Fly ash	Part of smoke released from chimneys of factories and power plants	Settles down on vegetation, houses. Addsto the suspended participate matter (SPM)in the air. Leachates contain harmful material

Particulate pollutants

Particulate matters suspended in air are dust and soot released from the industrial chimneys. Their size ranges from 0.001 to 500 µm in diameter. Particles less than 10µm float and move freely with the air current. Particles which are more than 10µm in diameter settle down. Particles less than 0.02 µm form persistent aerosols. Major source of SPM (suspended particulate matter) are vehicles, power plants, construction activities, oil refinery, railway yard, market place, industries, etc.

Fly ash

Fly ash is ejected mostly by thermal power plants as byproducts of coal burning operations. Fly ash pollutes air and water and may cause heavy metal pollution in water bodies. Fly ash affects vegetation as a result of its direct deposition on leaf surfaces or indirectly through its deposition on soil. Fly ash is now being used for making bricks and as a land fill material.

Lead and other metals particles

The lead particles coming out from the exhaust pipes of vehicles are mixed with air. If inhaled it produces injurious effects on kidney and liver and interferes with development of red blood cells. Lead mixed with water and food can create cumulative poisoning. It has long term effects on children as it lowers intelligence. Oxides of iron, aluminum, manganese, magnesium, zinc and other metals have adverse effect due to deposition of dust on plants during mining operations and metallurgical processes. They create physiological, biochemical and developmental disorders in plants and also contribute towards reproductive failure in plants.

Gaseous pollutants

Power plants, industries, different types of vehicles – both private and commercial use petrol, diesel as fuel and release gaseous pollutants such as carbon dioxide, oxides of nitrogen and sulphur dioxide along with particulate matter in the form of smoke. All of these have harmful effects on plants and humans. Table **8.3.2** lists some of these pollutants, their sources and harmful effects.

Table 8.3.2 Gaseous air pollutants: their sources and effects

Pollutant	**Source**	**Harmful effect**
Carbon compound(CO and	Automobile exhaust burning	•Respiratory problems

CO_2) Sulphur compounds(SO_2 and H_2S)Nitrogen Compound(NO and N_2O)Hydrocarbons(benzene, ethylene) ,SPM (Suspended,Particulate Matter)(Any soild and liquid, particles suspended in the air, (flush, dust lead) Fibres (Cotton, wool)	of wood and coal, Power plants and refineries, volcanic eruptions, Motor vehicle exhaust atmospheric reaction Automobiles and petroleum industries Thermal power plants, Construction activities, metalurgical processes and automobiles Textiles and carpet weaving industries	•Greenhouse effect •Respiratory problems in humans • Loss of chlorophyll in plants (chlorosis) •Acid rain Irritation in eyes and lungs • Low productivity in plants •Acid rain damages material (metals and stone) •Respiratory problem Cancer causing properties Poor visibility, breathing problems •Lead interfers with the development of red blood diseases and cancer. • Smoge (skoke & fog) formation leads to poor visibility and aggravates asthma in patients • Lung disorders

Prevention and control of air pollution

(i) Indoor air pollution

Poor ventilation due to faulty design of buildings leads to pollution of the confined space. Paints, carpets, furniture, etc. in rooms may give out volatile organic compounds. Use of disinfectants, fumigants, etc. may release hazardous gases. In hospitals, pathogens present in waste remain in the air in the form of spores. This can result in hospital acquired infections and is an occupational health hazard. In congested areas, slums and rural areas burning of firewood and biomass results in lot of smoke. Children and ladies exposed to smoke may suffer from acute respiratory problems which include running nose, cough, sore throat, lung infection, asthma, difficulty in breathing, noisy respiration and wheezing.

(ii) Prevention and control of indoor air pollution

Use of wood and dung cakes should be replaced by cleaner fuels such as biogas, kerosene or electricity. But supply of electricity is limited. Similarly kerosene is also limited. Improved stoves for looking like smokeless chullahs have high thermal efficiency and reduced emission of pollutants including smoke. The house designs should incorporate a well ventilated kitchen. Use of biogas and CNG (Compressed Natural Gas) need to be encouraged. Those species of trees such as baval (*Acacia nilotica*) which are least smoky should be planted and used. Charcoal is a comparatively cleaner fuel. Indoor pollution due to decay of exposed kitchen waste can be reduced by covering the waste properly. Segregation of waste, pretreatment at source, sterilization of rooms help in checking indoor air pollution.

(iii) Prevention and control of industrial pollution

Industrial pollution can be greatly reduced by:

a. Use of cleaner fuels such as liquefied natural gas (LNG) in power plants, fertilizer plants etc. which is cheaper in addition to being environmentally friendly.
b. Employing environment friendly industrial processes so that emission of pollutants and hazardous waste is minimized.
c. Installing devices which reduce release of pollutants. Devices like filters, electrostatic precipitators, inertial collectors, scrubbers, gravel bed filters or dry scrubbers are described below:
    i. **Filters** – Filters remove particulate matter from the gas stream. The medium of a filter may be made of fibrous materials like cloth, granular material like sand, a rigid material like screen, or any mat like felt pad. Bug-house filtration system is the most common one and is made of cotton or synthetic fibers (for low temperatures) or glass cloth fabrics (for higher temperature up to 290^{o}C).
    ii. **Electrostatic precipitators** - The emanating dust is charged with ions and the ionized particulate matter is collected on an oppositely charged surface. The particles are removed from the collection

surface by occasional shaking or by rapping the surface. ESPs are used in boilers, furnaces, and many other units of thermal power plants, cement factories, steel plants, etc.

iii. **Inertial collectors** – It works on the principle that inertia of SPM in a gas is higher than its solvent and as inertia is a function of the mass of the particulate matter this device collects heavier particles more efficiently. 'Cyclone' is a common inertial collector used in gas cleaning plants.

iv. **Scrubbers** – Scrubbers are wet collectors. They remove aerosols from a stream of gas either by collecting wet particles on a surface followed by their removal, or else the particles are wetted by a scrubbing liquid. The particles get trapped as they travel from supporting gaseous medium across the interface to the liquid scrubbing medium. Gaseous pollutants can be removed by absorption in a liquid using a wet scrubber and depends on the type of the gas to be removed e.g. for removal of sulphur dioxide alkaline solution is needed as it dissolves sulphur dioxide. Gaseous pollutants may be absorbed on an activated solid surface like silica gel, alumina, carbon, etc. Silica gel can remove water vapour. Condensation allows the recovery of many by products in coal and petroleum processing industries from their liquid effluents.

Apart from the use of above mentioned devices, other control measures are:

- *Increasing the height of chimneys.*
- *Closing industries which pollute the environment.*
- *Shifting of polluting industries away from cities and heavily populated areas.*
- *Development and maintenance of green belt of adequate width.*

iv. Control of vehicular pollution

- The emission standards for automobiles have been set, which if followed will reduce the pollution. Standards have been set for the durability of catalytic converters which reduce vehicular emission.
- In cities like Delhi, motor vehicles need to obtain Pollution under Control (PUC) certificate at regular intervals. This ensures that levels of pollutants emitted from vehicle exhaust are not beyond the prescribed legal limits.
- The price of diesel is much cheaper than petrol, which promotes use of diesel. To reduce emission of sulphur dioxide, sulphur content in diesel has been reduced to 0.05%.
- Earlier lead in the form of tetraethyl lead was added in the petrol to raise octane level for smooth running of engines. Addition of lead in petrol has been banned to prevent emission of lead particles with the vehicular emission.

Activities

1. *Which type of pollution is common in your area? Why?*
2. *Name any three devices that control pollution.*
3. *State two means of controlling indoor air pollution.*
4. *What is a PUC certificate?*

Global Warming and Greenhouse Effect

Atmospheric gases like carbon dioxide, methane, nitrous oxide, water vapour, and chlorofluorocarbons are capable of trapping the out-going infrared radiation from the earth. Infra-red radiations trapped by the earth’s surface cannot pass through these gases and to increase thermal energy or heat in the atmosphere. Thus, the temperature of the global atmosphere is increased. As this phenomenon of increase in temperature is observed in green houses, in the botanical gardens these gases are known as greenhouse gases and the heating effect is known as greenhouse effect. If greenhouse gases are not checked, by the turn of the century the temperature may rise by 5^0C. This will melt the polar ice caps and increase the sea level leading to coastal flooding, loss of coastal areas and ecosystems like swamps and marshes, etc.

Noise pollution

Noise is one of the most pervasive pollutants. A musical clock may be nice to listen during the day, but may be an irritant during sleep at night. Noise by definition is “sound without value” or “any noise that is unwanted by the recipient”. Noise in industries such as stone cutting and crushing, steel forgings , loudspeakers, shouting by hawkers selling their wares, movement of heavy transport vehicles, railways and airports leads to irritation and an increased blood pressure, loss of temper, decrease in work efficiency, loss of hearing which may be first temporary but can become permanent in the noise stress continues. It is therefore of utmost importance that excessive noise is controlled. Noise level is measured in terms of decibels (dB). W.H.O. (World Health Organization) has prescribed optimum noise level as 45 dB by day and 35 dB by night. Anything above 80 dB is hazardous. The table10.4 gives the noise intensity in some of the common activities.

Sources of noise pollution

Noise pollution is a growing problem. All human activities contribute to noise pollution to varying extent. Sources of noise pollution are many and may be located indoors or outdoors. Indoor sources include noise produced by radio, television, generators, electric fans, air coolers, air conditioners, different home appliances, and family conflict. Noise pollution is more in cities due to a higher concentration of population and industries and activities such as transportation. Noise like other pollutants is a byproduct of industrialization, urbanization and modern civilization.

Outdoor sources of noise pollution include indiscriminate use of loudspeakers, industrial activities, automobiles, rail traffic, airplanes and activities such as those at market place, religious, social, and cultural functions, sports and political rallies. In rural areas farm machines, pump sets are main sources of noise pollution. During festivals, marriage and many other occasions, use of fire crackers contribute to noise pollution.

Effects of noise pollution noise pollution are highly annoying and irritating. Noise disturbs sleep, causes hypertension (high blood pressure), emotional problems such as aggression, mental depression and annoyance. Noise pollution adversely affects efficiency and performance of individuals.

Prevention and control of noise pollution following steps can be taken to control or minimize noise pollution-

- Road traffic noise can be reduced by better designing and proper maintenance of vehicles.
- Noise abatement measures include creating noise mounds, noise attenuation walls and well maintained roads and smooth surfacing of roads.
- Retrofitting of locomotives, continuously welded rail track, use of electric locomotives or deployment of quieter rolling stock will reduce noises emanating from trains.
- Air traffic noise can be reduced by appropriate insulation and introduction of noise regulations for takeoff and landing of aircrafts at the airport.
- Industrial noises can be reduced by sound proofing equipment like generators and areas producing lot of noise.
- Power tools, very loud music and land movers, public functions using loudspeakers, etc should not be permitted at night. Use of horns, alarms, refrigeration units, etc. is to be restricted. Use of fire crackers which are noisy and cause air pollution should be restricted.
- A green belt of trees is an efficient noise absorber.

Activities

1. What is noise and in which units it is measured?

2. State two harmful effects of noise pollution.

3. State two important indoor and two outdoor sources of noise pollution? Mention method of control for each of them.

2. Water pollution

Addition or presence of undesirable substances in water is called water pollution. Water pollution is one of the most serious environmental problems. Water pollution is caused by a variety of human activities such as industrial, agricultural and domestic. Agricultural runoff laden with excess fertilizers and pesticides, industrial effluents with toxic substances and sewage water with human and animal wastes pollute our water thoroughly. Natural sources of pollution of water are soil erosion, leaching of minerals from rocks and decaying of organic matter. Rivers, lakes, seas, oceans, estuaries and ground water sources may be polluted by point or non-point sources. When pollutants are discharged from a specific location such as a drain pipe carrying industrial effluents discharged directly into water body it represents point source pollution. In contrast non-point sources include discharge of pollutants from diffused sources or from a larger area such as runoff from agricultural fields, grazing lands, construction sites, abandoned mines and pits, roads and streets.

Sources of water pollution

Water pollution is the major source of water born diseases and other health problems. Sediments brought by runoff water from agricultural fields and discharge of untreated or partially treated sewage and industrial effluents, disposal of fly ash or solid waste into or close to a water body cause severe problems of water pollution. Increased turbidity of water because of sediments reduces penetration of light in water that reduces photosynthesis by aquatic plants.

(i) Pollution due to pesticides and inorganic chemicals

- Pesticides like DDT and others used in agriculture may contaminate water bodies. Aquatic organisms take up pesticides from water get into the food chain (aquatic in this case) and move up the food chain. At higher trophic level they get concentrated and may reach the upper end of the food chain.
- Metals like lead, zinc, arsenic, copper; mercury and cadmium in industrial waste waters adversely affect humans and other animals. Arsenic pollution of ground water has been reported from West Bengal, Orissa, Bihar and Western Utara paradish(U.P). Consumption of such arsenic polluted water leads to accumulation of arsenic in the body parts like blood, nails and hairs causing skin lesions, rough skin, dry and thickening of skin and ultimately skin cancer.
- Pollution of water bodies by mercury causes Minamata disease in humans and dropsy in fishes. Lead causes displexia, cadmium poisoning causes Itai – Itai disease etc.

• Oil pollution of sea occurs from leakage from ships, oil tankers, rigs and pipelines. Accidents of oil tankers spill large quantity of oil in seas which kills marine birds and adversely affects other marine life and beaches.

(ii) Thermal pollution

Power plants- thermal and nuclear, chemical and other industries use lot of water (about 30 % of all abstracted water) for cooling purposes and the used hot water is discharged into rivers, streams or oceans. The waste heat from the boilers and heating processes increases the temperature of the cooling water. Discharge of hot water may increase the temperature of the receiving water by 10 to 15 °C above the ambient water temperature is called thermal pollution. Increase in water temperature decreases dissolved oxygen in water which adversely affects aquatic life. Unlike terrestrial ecosystems, the temperature of water bodies remains steady and does not change very much. Accordingly, aquatic organisms are adapted to a uniform steady temperature of environment and any fluctuation in water temperature severely affects aquatic plants and animals. Hence discharge of hot water from power plants adversely affects aquatic organisms. Aquatic plants and animals in the warm tropical water live dangerously close to their upper limit of temperature, particularly during the warm summer months. It requires only a slight deviation from this limit to cause a thermal stress to these organisms. Discharge of hot water in water body affects feeding in fishes, increases their metabolism and affects their growth. Their swimming efficiency declines. Running away from predators or chasing prey becomes difficult. Their resistance to diseases and parasites decreases. Due to thermal pollution biological diversity is reduced. One of the best methods of reducing thermal pollution is to store the hot water in cooling ponds, allow the water to cool before releasing into any receiving water body

Ground water pollution Lot of people around the world depend on ground water for drinking, domestic, industrial and agricultural uses. Generally groundwater is a clean source of water. However, human activities such as improper sewage disposal, dumping of farm yard manures and agricultural chemicals, industrial effluents are causing pollution of ground water.

Eutrophication - 'Eu' means well or healthy and 'trophy' stands for nutrition. The enrichment of water bodies with nutrients causes entrophication of the water body. Discharge of domestic waste, agricultural surface runoff, land drainage and industrial effluents in a water body leads to rapid nutrients enrichment in a water body. The excessive nutrient enrichment in a water body encourages the growth of algae duckweed, water hyacinth, phytoplankton and other aquatic plants. The biological demand for oxygen (BOD) increases with the increase in aquatic organisms. As more plants grow and die, the dead and decaying plants and organic matter acted upon by heterotrophic prtozoans and bacteria, deplete the water of dissolved oxygen (DO). Decrease in DO result in sudden death of large population of fish and other aquatic organisms including plants, releasing offensive smell and makes the water unfit for human use. The sudden and explosive growth of phytoplankton and algae impart green colour to the water is known as water bloom, or "algal blooms". These phytoplankton release toxic substances in water that causes sudden death of large population of fishes. This phenomenon of nutrient enrichment of a water body is called eutrophication. Human activities are mainly responsible for the eutrophication of a growing number of lakes and water bodies in the country.

Methods for control of water pollution and water recycling

Control water pollution

Waste water from domestic or industrial sources or from garbage dumps is generally known as sewage. It may also contain rain water and surface runoff. The sewage water can be treated to make it safe for disposal into water bodies like rivers, lakes etc. The treatment involves three stages: primary, secondary and tertiary. This includes: Sedimentation, coagulation/flocculation, filtration, disinfection, softening and aeration. The first four steps are primary treatment. The first three steps are involved in primary treatment remove suspended particulate matter. Secondary treatment removes organic solids, left out after primary treatment, through their microbial decomposition. Effluents after secondary treatment may be clean but contain large amounts of nitrogen, in form of ammonia, nitrates and phosphorous which can cause problem of eutrophication upon their discharge into a receiving water body such as river, lake or pond. The tertiary treatment is meant to remove nutrients, disinfect for removing pathogenic bacteria, and aeration removes hydrogen sulphide and reduce the amount of carbon dioxide and make water healthy and fit for aquatic organisms. This treatment of waste water or sewage is carried out in effluent treatment plants especially built for this purpose. The residue obtained from primary treatment one known as sludge.

Water recycling with increasing population the requirement for water is increasing rapidly. However, the availability of water is limited but an ever increasing water withdrawal from different sources such as rivers, lakes and ground water is depleting these sources and deteriorating their water quality. Therefore, it is essential to utilize the available water with maximum economy. This involves recycling of waste water for certain uses with or without treatment. Recycling refers to the use of waste-water by the original user prior to the discharge either to a treatment system or to a receiving water body. Thus the waste water is recovered and repetitively recycled with or without treatment by the same user.

Control of water pollution

The following measures can be adopted to control water pollution:

(a) The water requirement should be minimized by altering the techniques involved.

(b) Water should be reused with or without treatment.

(c) Recycling of water after treatment should be practiced to the maximum extent possible. (d) The quantity of waste water discharge should be minimized.

Activities

1. Name the metals in water that cause Minamata and Itaiitai diseases.
2. When fertilizers and sewage enter a water body, phytoplankton and algae grow rapidly. What is this phenomenon?
3. What is primary treatment?
4. The water used for cooling purposes in industries may be drained industrial into rivers. To what extent does this raise the water temperature of the river?
5. What effect does thermal pollution have on the swimming efficiency of fish?
6. What effect does thermal pollution have on metabolism of aquatic animals?
7. State the term for residue left after primary treatment of waste water.

3. Soil pollution

Addition of substances which adversely affect the quality of soil or its fertility is known as soil pollution. Generally polluted water also pollutes soil. Solid waste is a mixture of plastics, cloth, glass, metal and organic matter, sewage, sewage sludge, building debris, generated from households, commercial and industries establishments add to soil pollution. Fly ash, iron and steel slag, medical and industrial wastes disposed on land are important sources of soil pollution. In addition, fertilizers and pesticides from agricultural use which reach soil as run-off and land filling by municipal waste are growing cause of soil pollution. Acid rain and dry deposition of pollutants on land surface also contribute to soil pollution.

Sources of soil pollution

Plastic bags made from low density polyethylene (LDPE), is virtually indestructible, create colossal environmental hazard. The discarded bags block drains and sewage systems. Leftover food, vegetable waste etc. on which cows and dogs feed may die due to the choking by plastic bags. Plastic is non-biodegradable and burning of plastic in garbage dumps release highly toxic and poisonous gases like carbon monoxide, carbon dioxide, phosgene, dioxine and other poisonous chlorinated compounds.

Industrial sources: It includes fly ash, chemical residues, metallic and nuclear wastes. Large number of industrial chemicals, dyes, acids, etc. find their way into the soil and are known to create many health hazards including cancer.

Agricultural sources :Agricultural chemicals especially fertilizers and pesticides pollute the soil. Fertilizers in the runoff water from these fields can cause eutrophication in water bodies. Pesticides are highly toxic chemicals which affect humans and other animals adversely causing respiratory problems, cancer and death.

Control of soil pollution

Indiscriminate disposal of solid waste should be avoided. To control soil pollution, it is essential to stop the use of plastic bags and instead use bags of degradable materials like paper and cloth. Sewage should be treated properly before using as fertilizer and as landfills. The organic matter from domestic, agricultural and other waste should be segregated and subjected to vermicomposting which generates useful manure as a byproduct. The industrial wastes prior to disposal should be properly treated for removing hazardous materials. Biomedical waste should be separately collected and incinerated in proper incinerators.

Activities

1. Define soil pollution.
2. Why are plastic bags a big environmental nuisance?
3. How vermicomposting degrades organic waste into a useful substance? What is this substance used for?

Radiation pollution: sources and hazards

Radiation pollution is the increase in over the natural background radiation. There are many sources of radiation pollution such as nuclear wastes from nuclear power plants, mining and processing of nuclear material etc. The worst case of nuclear pollution was the cherndoyl disaster in Russia occurred in 1986 but the effects still longer today.

Radiation is a form of energy travelling through space. The radiations emanating from the decay of radioactive nuclides are a major sources of radiation pollution. Radiations can be categorized into two groups namely the non-ionizing radiations and the ionizing radiations.

Non-ionizing radiations are constituted by the electromagnetic waves at the longer wavelength of the spectrum ranging from near infra-red rays to radio waves. These waves have energies enough to excite the atoms and molecules of the medium through which they pass, causing them to vibrate faster but not strong enough to ionize them. In a microwave oven the radiation causes water molecules in the cooking medium to vibrate faster and thus raising its temperature.

Ionizing radiations cause ionization of atoms and molecules of the medium through which they pass. Electromagnetic radiations such as short wavelength ultra violet radiations (UV), X-rays and gamma rays and energetic particles produced in nuclear processes, electrically charged particles like alpha and beta particles produced in radioactive decay and neutrons produced in nuclear fission, are highly damaging to living organisms. Electrically charged particles produced in the nuclear processes can have sufficient energy to knock electrons out of the atoms or molecules of the medium, thereby producing ions. The ions produced in water molecules, for example, can induce reactions that can break bonds in proteins and other important molecules. An example of this would be when a gamma ray passes through a cell, the water molecules near the DNA might be ionized and the ions might react with the DNA causing it to break. They can also cause chemical changes by breaking the chemical bonds, which can damage living tissues. The ionizing radiations cause damage to biological systems and are, therefore, pollutants.

Radiation damage the biological damage resulting from ionizing radiations is generally termed as radiation damage. Large amounts of radiation can kill cells that can dramatically affect the exposed organism as well as possibly its offspring. Affected cells can mutate and result in cancer. A large enough dose of radiation can kill the organism. Radiation damage can be divided into two types:

(a) **Somatic damage** (also called radiation sickness) and

(b) Genetic damage. Somatic damage refers to damage to cells that are not associated with reproduction. Effects of somatic radiation damage include reddening of the skin, loss of hair, ulceration, fibrosis of the lungs, the formation of holes in tissue, a reduction of white blood cells, and the induction of cataract in the eyes. This damage can also result in cancer and death. Genetic damage refers to damage to cells associated with reproduction. This damage can subsequently cause genetic damage from gene mutation resulting in abnormalities. Genetic damages are passed on to next generation.

Radiation dose-the biological damage caused by the radiation is determined by the intensity of radiation and duration of the exposure. It depends on the amount of energy deposited by the radiation in the biological system. In studying the effects of radiation exposure in humans, it is important to realize that the biological damage caused by a particle depends not only on the total energy deposited but also on the rate of energy loss per unit distance traversed by the particle (or "linear energy transfer"). For example, alpha particles do much more damage per unit energy deposited than do electrons.

Radiation effects and radiation doses-A traditional unit of human-equivalent dose is the rem, which stands for radiation equivalent in man. At low doses, such as what we receive every day from background radiation (< 1 m rem), the cells repair the damage rapidly. At higher doses (up to 100 rem), the cells might not be able to repair the damage, and the cells may either be changed permanently or die. Cells changed permanently may go on to produce abnormal cells when they divide and may become cancerous. At even higher doses, the cells cannot be replaced fast enough and tissues fail to function. An example of this would be "radiation sickness." This is a condition that results after high doses is given to the whole body (>100 rem). Nuclear explosions and accidents in nuclear reactors are a serious source of radiation hazard. The effects of atomic explosions in Nagasaki and Hiroshima are still not forgotten. The nuclear reactor accident at Chernobyl in 1986 led to deaths of many reactor personnel and a very large release of radionuclide to the environment causing long term radiation damage to the people living in the neighboring regions.

Accidents at nuclear power plants nuclear fission in the reactor core produces lot of heat which if not controlled can lead to a meltdown of fuel rods in the reactor core. If a meltdown happens by accident, it will release large quantities of highly dangerous radioactive materials in the environment with disastrous consequences to the humans, animals and plants. To prevent this type of accidents and reactor blow up, the reactors are designed to have a number of safety features. Inspite of these safety measures two disasters in the nuclear power plants are noteworthy- namely at 'Three Mile Island' in Middletown (U.S.A.) in 1979, at Chernobyl (U.S.S.R.) in 1986. In both these cases a series of mishaps and errors resulted in over heating of the reactor core and lot of radiation was released into the environment. The leakage from Three Mile Island reactor was apparently low and no one was injured immediately. However, in case of Chernobyl the leakage was very heavy causing death of some workers and radiation spread over large areas scattered all over Europe. People of the city had to be evacuated to safer places and the plant had to be closed down. These two disasters are a reminder that nuclear power reactors require a constant up gradation of safety measures. Accidents with nuclear submarines also points to the same.

Activities

1. Which type of radiations are produced in a microwave oven?
2. State the use of absorbed dose of radiation.
3. How much of radiation can damage internal organs upon its exposure for a few days?
4. What are ionizing and non-ionizing radiations? Give examples.

Unit 9

Introduction to Botany and Zoology

Learning objectives

After completion of this unit, you will be expected to:

- describe features of algae
- explain different characteristics of algae
- describe the major features of bryophytes and pteridophytes
- what are the major features and groups of seed plants
- Define invertebrates and vertebrates
- Identify and use key features to differentiate between invertebrate groups
- Differentiate the characteristics of vertebrates
- Classify invertebrates and vertebrates animals
- Services provided by invertebrates

9.1 Introduction to Botany

Brain Storming Questions

1. What is Botany?
2. What are various branches of botany?
3. What organisms are addressed/studied under each sub disciplines of botany

Botany is one of the main branches of Biology concerned with the scientific study of plants. Botany has several branches. Like algology, bryology, pteridology, plant physiology, plant ecology, plant anatomy, plant nutrition, plant pathology, dendrology, phytochemistry, cell biology, histology, phytopathology, phytogeography, geobotany, paleobotany, cell phytopathology, phytogeography, geobotany and paleobotany are some of the major branches.

9.1.1 Algology

Algology (phycology) is a branch of botany deals with algae. It is derived from two Greek words: Phycos=algae; Logos=study. This discipline deals with the morphology, phylogeny (tree of Life), biology, reproduction and ecology of algae in all ecosystems. Algae can be defined as:simple, eukaryotic, autotrophic, have a various range of cell morphologies and diversified life cycle organisms. They differ widely in their distribution, structure, biochemical traits and eproduction(sexual and asexual). They lack the roots, stems, leaves & vascular tissues.Algae show the following major morphological variations:

- ✓ **Unicellular:s**ingle celled algae.
- ✓ **Colonial:** An assemblage of individual cells together.
- ✓ **Filamentous:**a morphology in which daughter cells remain attached after cell division.
- ✓ **Siphonaceaous:** a morphology in which one large, multi-nucleate cell without cross walls.

Algae reproduce both asexually and sexually. The common methods of asexual reproductions are: binary fission, fragmentation, hormogonia and spore production. Isogamy and heterogamy are the two common sexual reproduction methods.

Ecology and Distribution of Algae

Generally, algae can be found everywhere in nature. They are found from marine to fresh water, terrestrial land, shaded areas, etc. Various terminologies are applied for microhabitats of algae. For example, Epipelic: algae live on clay; Epipamic:algae live onsand; **Epilithic:** algae live onrocks; **Epiphytic:**algae live/grow on other plants; **Endozoic/epizoic:** Live in or on animals

Currently, there are different divisions of algae. The most common are listed below.

- **Cyanophyta:**a group of blue green algae includes *Nostoc, Anabaena, Spirullin, Oscilatotia, etc.*
- **Chlorophyta:** a group of green algae includes *Spirogyra, Volvox, Oedogonium, Chlorella,* and others.
- **Phaeophyta:** a group of brown algae includes *Fucus, Laminaria, Sargassum, Ectocarpus*
- **Rhodophyta:** a group of red algae includes *Polysiphonia, Coralline, etc.*
- **Charophyta:** Commonly known as stoneworts, usually preferred less oxygenated & hard water (Ca and Mg carbonates) areas.Example *Chara, Vaucheria*, etc.
- **Euglenophyta:** Unicellular fresh water algae, plant-animal feature. Example Euglena.
- **Bacillariophyta:** Especial group of algae, abundant in sediments in marine and freshwater ecosystems. Example Diatoms.

Economical uses of Algae

Algae have various economical uses like:

- ✓ Primary Producers
- ✓ As Fertilizers
- ✓ Sources of Iodine
- ✓ In biological research
- ✓ Pharmaceutical, cosmetic, and industrial applications
- ✓ Source of different compounds, like: agar, carrageenansand alginates
- ✓ Applications in Pisciculture
- ✓ Biofuel production
- ✓ Carbon sequestration
- ✓ Bioremediation

9.1.2 Bryology and Pteridology

Bryology is a science mosses and liverworts (Bryophyta). Pteridology is the science of ferns and their relatives. Division Bryophyta is divided in to 3 classes. These are:

- Class Hepaticopsida (Liverworts)
- Class Anthocertopsida (Hornworts)
- Class Bryopsida (Mosses)

Liverworts are given their name because the lobes of their gametophyte plant resemble to the liver of human, wort - means "plant". Most species are leafy resemble mosses while others are thaloid superficially resembling lichens. Their thallus is attached to the substrate by unicellular rhizoids. There are about 8500 species of liverworts. Liverworts range in size from tiny, leafy filaments less than 0.5 mm in diameter to a thallus more than 20 cm wide.

Fig: 9.1.*Marchantia* (Liverwort)

Hornworts are a group of small, inconspicuous thaloid plants that often grow on moist soils. They consist of only about 400 named species. They are different from all other embryophytesin having a single large chloroplast (occasionally two to four) per cell and chloroplasts have a pyrenoid, both algal feature and absent in all other embryophytes.

Mosses are perennial & remarkably successful plants. Although the mosses are small plants, they are conspicuous (their wide range of habitats, soft texture and pleasant green appearance). About 12,000 species of mosses are known. They are the largest and most familiar group of bryophytes.

The division Pteridophytes also categorized in to four main groups. Namely Psilophyta, Lycopsida(containing lycopodiales, selaginellales, isoetes), Sphenopsida and Pteropsida.Psilophyta are characterized by aerial stem, bear small scale like leaves that are epidermal in origin. This scale like leaves (Prophylls) do not have vascular tissues which resemble the leaves of bryophyte in having no vascular strand and regarded as appendages rather than true leaves. Like all other vascular plants, Psilotales possess stomata, but unlike other vascular plants the stomata are found in the epidermis of the stem.

Lycophyta are also characterized or distinguished form members of Psilotals by having true leaves and roots; by association of their sporangia with fertile leaves-sporophylls. They are known as club mosses because of their small size and their moss like leaves. Dear students, please read about different divisions of Pteridophytes from various books.

9.1.3 Seed plants

Another important and dominant group of plants are called seed plants. Seed is the product of the fertilized ovule. Seed is a culmination of the activities of one plant generation and the start of a new one that contains embryo for survival value. The plant world is dominated by gymnosperms and angiosperms, which are collectively known as **seed plants** or**spermatophytes.** They are the most important plants on Earth unlike other seedless plants (mosses, liverworts, horsetails), which are overlooked because of their size or inconspicuous appearance. Life on land as we know it is shaped largely by the activities of seed plants. Soil, forest, and food are some of the most apparent products of this group.

The angiosperms or flowering plants are the most advanced one now a day.Most land plants familiar to us belong to this groupincludes from grasses to cactuses, tiny herbs to large trees. This huge and diverse group is divided again into two subgroups; **monocotyledons** (grasses, crops, lilies and palms) and **dicotyledons**(Olea, Ficus, beans, peas, chickpea, etc…).

Seeds contain: embryo, food, endosperm, seed coat or testa and sporophyte. The **embryo** within the seed is dormant; it can survive for long periods without additional food or water. When conditions become favorable, the embryo resumes growth as the seed germinates i. e upon germination the seeds produce the sporophyte. Seeds have freedom from external water for transfer of the male gamete or spermatozoids to the female gamete or egg cells. They produce pollen and pollen tube. **Endosperm** provides nourishment or food supply for the growing embryo (young sporophyte).

Seed plants have distinct features. They produce two major features that distinctly distinguish them from other plants. The first is the **seed.** The production of seed is a very advanced stage in plant life. The second is **wood.** The possession of wood is also another very important feature. Therefore, the production of seed and wood, which other non-seed plants cannot produce are unique features.

Seed plants have also have other many features in common, like:

- ❑ The **dominant** phase is represented by the **sporophyte**, which is differentiated into roots, stems and leaves or shoot.
- ❑ The leaves of seed plants are **megaphyllous.**
- ❑ The **gametophytes** (male and female) are protected from desiccation and injury by the protective covering of the ovules called **integuments** and later embryo is protected by the **seed coat** or**testa**.

The generalized life cycle of seed plants, which have separate male and female gametophytes produced by different sized spores is indicated below the Figure.

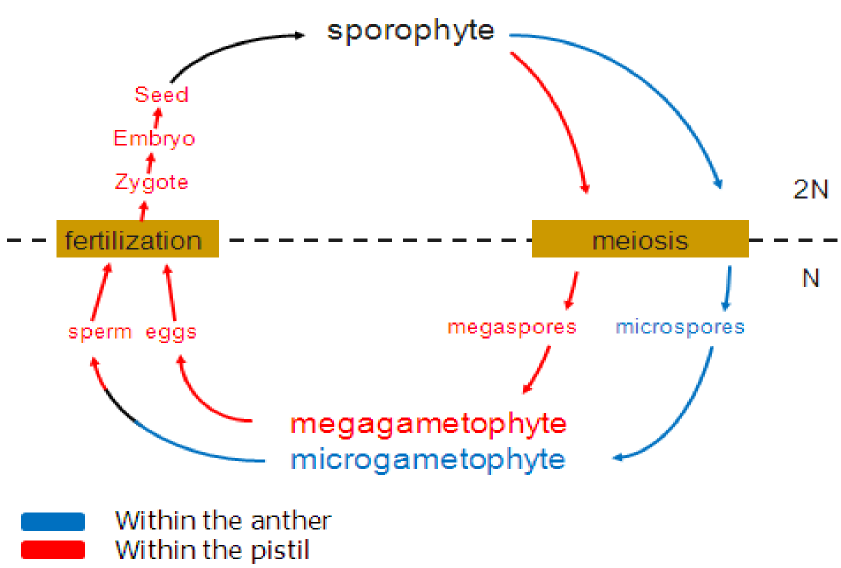


Fig:9.2. Generalized life cycle of seed plants

Seed plants are broadly divided in to two. These are Gymnosperms and angiosperms. The following are common characteristics of gymnosperms.

Gymnospermsare distinguished from angiosperms recently. At one time, they were considered to be a single class of seed plants. The term gymnosperm derived from two Greek words (gymnos- naked, sperma-seed=naked seed plants). Plants with seeds that are not enclosed within a fruit- seeds are produced on the open surface of the cones or cups. They do not form true flowers and fruits. They were the first true seed plants. Most are tall evergreen trees with roots, wood and stems. They are needle shaped leaves. Have vascular tissues for transport and reproductive structures are found on cones. Seeds are found in female cones.

Angiosperms are the largest group of seed plants with about 90% of all plant species. Their name Angiosperm derived from Greek words, Angio-container/vessel and sperma- seed= seed enclosed in vessel or fruits. They are the most abundant and recognized plants. These plants are a gain divided into two main groups (monocots and dicots) based on cotyledons. They produce seeds in flowers they do have fruits and advanced vascular tissues.

9.2 Introduction to zoology

9.2.1 Invertebrates

There are over a million described species of animals. Of this number about 5% possess a backbone and are known as vertebrates. All others, constituting the greater part of the animal kingdom, are invertebrates. The Invertebrates therefore include 95% of all species in the animal kingdom plus more than half of the animal-like members of the kingdom protista.

Self-test

1. Write the general characteristics of invertebrates.
2. List down major classes of invertebrates

9.2.1.1 General Characteristics of Invertebrates

→ Invertebrates are animals without backbones.

→ Invertebrates are by far the most numerous animals on earth and heterogeneous assemblage of groups that do not hold a single positive characteristic in common.

→ Invertebrates are multicellular, heterotrophs and motile animals but the adult forms of some lower invertebrate species are sessile, belonging to a group of filter feeders.

→ Invertebrates are varying in size, in structural diversity, and in adaptations to different modes of existence.

→ Invertebrates able to exhibit all types of reproduction.

→ Invertebrates can be categorized as acoelomates, pseudocoelomates or coelomates.

→ Invertebrates show radial symmetry, bilateral symmetry or they may be assymetric.

→ Invertebrates are with different stages of organization.

→ Some invertebrates have common phylogenetic origin; others are only remotely related. Some are much more closely related to the vertebrates than to other invertebrate groups.

9.2.1.2 Classification of Invertebrates

Zoologists classify invertebrates into different major groups, known as phyla. These phyla vary enormously in the number of species they contain. The major phyla include the following:

A. Phylum Porifera (Sponges)

The word Porifera has been adopted from the Latin porus for pore and Ferre to bear, hence sponges are called “pore bearing animals” since their body wall is perforated by numerous tiny pores. The phylum comprises the most primitive and simple multicellular animals that lack organs. Compared with other metazoans, sponges’s cells show a high degree of interdependence that the sponge body resembles a protozoan colony in some respects. Major classes of Porifera: Class Calcarea (calcispongiae), Class Hexactinellida (Hyalospongiae) or 'Glass sponges', and Class Demospongiae

B. Phylum Radiata

The first groups of true Metazoa (Eumetazoa) are called radiates. The Eumetazoa can be divided into the Radiata**,** which are characterized by a primary radial or biradial symmetry, and the Bilateria**,** which have a bilateral symmetry. The Radiata are the most primitive of the Eumetazoa. The radiate animals are made up of two phyla, namely Cnidaria and Ctenophora, which have got their common name from the type of symmetry they have. Cnidaria have two basic body plans: polyp and medusa.

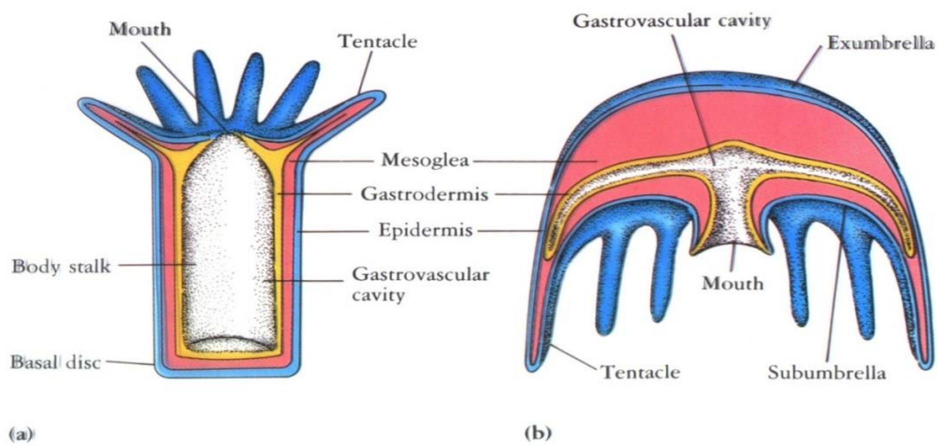


Fig.9.1: a) Polypoid body form. b) Medusoid body form

C. Acoelomate Bilateria

Common features of Acoelomates

- Have no coelom (body cavity). The space between the body wall and the digestive tract is filled with muscle fibers and loose tissue called parenchyma. They have bilateral symmetry and defined tissues organized into functional organs. They have a highly organized nervous system with concentration of nervous tissue and sense organs in the anterior end (cephalization), excretory system of specialized flame cells and tubules for elimination of nitrogenous wastes.
- Acoelomates include:

  -flatworms, phylum Platyhelminthes (Gr. *platys,* flat, + *helmins,* worm)

  -ribbon worms, phylum Nemertea (Gr. *Nemertes,* one of the Nereids, mermaids of Greek mythology) and

  -Jaw worms, phylum Gnathostomulida (Gr. *gnathos,* jaw, + *stoma,* mouth).

- Flatworms (phylum Platyhelminthes) are divided into four classes:

1. Class Turbellaria – Free living Flatworms
2. Class Trematodes - parasitic flukes
3. Class Monogenea – parasitic monogenetic flukes
4. Class Cestoda – tapeworms

D. Phylum Nematoda (Roundworms)

General characteristics

-Are pseudocoelomate and there are more than 25,000 species.

Nematodes are an extensive group with worldwide distribution.

Bilateral symmetry, Triploblastic structure (endoderm, mesoderm and ectoderm)

Some degree of cephalization = head with sensory organs, they are elongated roundworms covered with a flexible, nonliving cuticle, lack both cilia and flame cells/bulbs, free living, aquatic, terrestrial and many parasitic

- ❖ A handful of good garden soil contains thousands of nematodes.
- ❖ Some nematodes are plant parasites feeding on plant sap, especially roots.
- ❖ *Caenohabditis elegans*, a free-living nematode
    - o Easy to culture in the laboratory and has become an individual mode**l** for studies of basic developmental biology.
- ❖ **Dioecious**; sexes separate with females larger than males; **one** or **two tubular gonads**; **Copulatory spicules** present in males

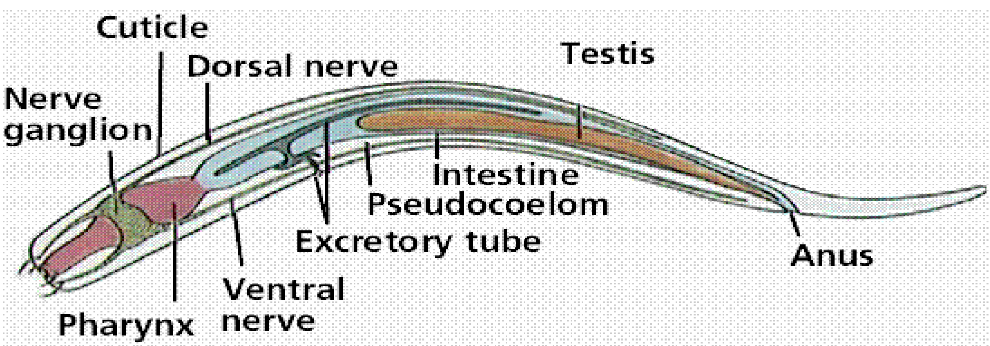


Fig.9.2 Typical nematode

Examples of some nematode parasites

Nematodes are parasitic in humans, cats, dogs, and domestic animals of economic importance, such as cows and sheep. They are also parasitic on the roots, stems, leaves, and flowers of plants.

- Giant Intestinal Roundworm (*Ascaris lumbricoides*)

-Hookworm

-Filarial worms, Pinworm (*Enterobius vermicularis*)

-Porkworm (*Trichinella spiralis*) –Humans infected by eating improperly cooked pork

-Dog heartworms (*Dirofilaria immitis)*

E. Coelomate Animals: Protostomes Vs Deutrostomes

Protostomes exhibit determinate development. In this type of development, each embryonic cell has a predetermined fate in terms of what kind of tissue it will form in the adult.

Deuterostomes, on the other hand, display indeterminate development. The first few cell divisions of the egg produce identical daughter cells. Any one of these cells, if separated from the others, can develop into a complete organism.

In protostomes, the egg cleaves spirally, and the blastopore becomes the mouth. In deuterostomes, the egg cleaves radially, and the blastopore becomes the anus.

In all coelomates, the coelom originates from mesoderm. In protostomes, coelom produced simply and directly from the mesoderm. However, in deuterostomes the coelom is normally produced by an evagination of the archenteron—the central tube within the gastrula, also called the primitive gut. This tube, lined with endoderm, opens to the outside via the blastopore and eventually becomes the gut cavity.

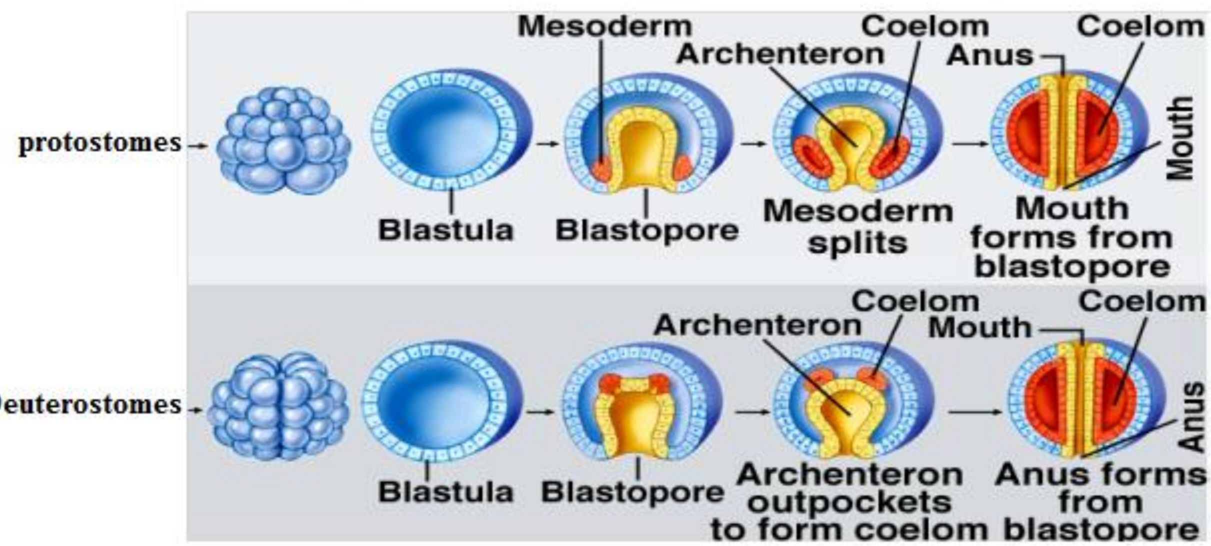


Fig 9.3 Embryonic development of Protostomes and Deutrostomes

Phylum Annelida (segmented worms, bristle worms)

- ✓ Annelids take their name from the Latin *anellus*, meaning "little ring", and refers to the ringlike constriction of the body.
- ✓ The Annelida are a medium sized phylum of more than 9,000 species of worms.

-Most species prefer aquatic environments, but there are also a number of well known terrestrial species. They include earthworms, sand worms, bristle worms, clam worms, fan worms, leeches.

-The fluid that fills the coelom serves a variety of functions.

- transports gases and nutritive materials
- provides fluid for processing excretory wastes
- functions as a hydrostatic skeleton, and
- a site for gamete maturation and brooding of embryos.

Classification of phylum Annelida includes:

a) Class – Polychaeta (Tubeworms, Clamworms, and Fanworm

b) Class Oligochaeta (e.g Earthworms)

c) Class Hirudinea(e.g. Leech)

Phylum Arthropoda: **Major Characteristics are listed as following:**

The name *Arthropoda* means "jointed foot" , are the most successful of all animals and represents ~ 80% of animal kingdom both in species and ecological distribution. Over a million species have been identified. Their body is divided into 3 sections: head , thorax (mid-body region) and abdomen

They have exoskeleton- The rigid outer layer of the arthropod body , composed primarily of the carbohydrate *chitin*, provides protection against predators and helps prevent water loss., an exoskeleton does not grow, arthropods shed their exoskeleton periodically and form a new, larger one.

Classification includes:

I. Subphylum Trilobita

II. Subphylum Chelicerata

Class Merostomata (horse-shoe crab)

Class Arachnida(spiders, scorpions, mites and ticks)

III. Subphylum Crustacea (shrimp, lobsters, Crayfish, water fleas, copepod & sow bugs)

1. Class Malacostraca

– Order Decapoda

– Order Isopoda

2. Class Branchiopoda

3. Class Osracoda

4. Class Maxillopoda

- Subclass Copepoda
- Subclass Thecostraca
  - Infraclass Cirripoda

IV. Subphylum Myriapoda

- Class Diplopoda (eg millipedes)
- Class Chilopoda (eg centipedes)

V. Subphylum Hexapoda

–Class Insecta (insects)

Classification of class insecta

I. Subclass Aperygota (No wings)

Order Thysanura – silverfish (no metamorphosis (Ametabolous))

II. Subclass Perygota (with wings)

1. Superorder Exopterygota (incomplete metamorphosis)

1. Order Isoptera (termites)
2. Order Odonata (dragonfly)
3. Order Blattaria (cockroach)
4. Order Orthoptera (grasshopper,crickets)
5. Order Mantodea (praying mantis)
6. Order Hemiptera – true bugs
7. Order Homoptera – plant lice, lacewings

2. Superorder Endopterygota (complete metamorphosis)

1. Order Lepidoptera (butterfly) - Scaly wings
2. Order Diptera (house fly, mosquito)
3. Order Coleoptera (beetle)
4. Order Hymenoptera (ants, bees, wasps)

Activities

1. Compare and contrast the polyp and medusa forms of cnidarians
2. Describe the structure and function of the stinging cells for which cnidarians are named.

9.2.1.3 Services Provided by Invertebrates

Self test: How do invertebrates contribute for the betterment of human being?

Ecosystem Services provided by Invertebrates consists of the following:

- Pollination- many cross pollinated plants depend on insects for pollination and fruit set. Eg Honey bees, aid in pollination of crops.
- Seed dispersal, natural enemies of other pests, decomposition
- Soil formation: Soil invertebrates include ecosystem engineers that are powerful drivers of soil physical functions (water dynamics, aeration and protection from erosion hazards). They play an important role in carbon cycling, as they control the carbon sequestration process and influence greenhouse gas emission. Example, soil insects such as ants, beetles, larval of cutworms, crickets, collumbola, make tunnels in soil and facilitate aeration in soil. They become good manure after death and enrich soil.

Invertebrates as a Resource

Example

- Source of food for humans, bait for fishing(Sponges for bathing), Corals, Conchs, Oysters and others for jewelry,
- Bees as pollinators of crops: Honey bees are mass produced and transported to farms during flowering periods to insure adequate pollination of crop plants, without pollination fruits and vegetables from insect pollinated crops will not be produced.

- Wasps, beetles, mantids, spiders, for biocontrol
- Medicinal use of leeches: Medicinal leeches are still used to reduce bruising and scarring after surgery
- Target of bio-prospecting: Invertebrates could serve as a source of biochemicals useful in medicine and other applications
- Cloth production (silk from- silkworm)

Fig 9.4. Silk worm

Pharmacologically active Compounds from Invertebrates

- Ecteinascidin – from tunicates – tested for treatment of breast and ovarian cancers
- Topsentin – from sponges – anti-inflammatory
- Lasonolide – from sponge (*Forcepia sp*). – anti-tumor
- Discodermalide – from sponges (*Discomermia*) – anti-tumor Bryostatin – from Bryozoan (*Bugula neritina*) – anti cancer
- Pseudopterosins – from octocoral (*Pseudoterogorgia elisabethae*) – anti-infammatory and analgesic agents that reduce swelling and skin irritation
- Omega Conotoxin MVIIA – extracted from cone snails (*Conus magnus*) – potent pain killer

Invertebrates as Food

Examples

- Mollusca (squid, mussels, clams, oysters, scallops, snails, abalone), Crustacea (shrimp, lobsters, crabs, spider crabs), Insecta (beetles, ants, termites, grasshoppers, bees), Echinodermata (sea cucumbers, sea urchins), Cnidaria (jellyfish) and Annelida (palolo worms)
- Bait for Fishing. For example: Earthworms (Oligochaeta), Insect larvae (Neuroptera – night crawlers) , Shrimp, etc.
- Invertebrate used in Jewelry includes**:** Morpho butterflies, Scarab beetles**,** Rare corals and Oysters and Conchs for pearl and mother of pear

9.2.2 Subphylum Vertebrates

9.3.1 Characteristics of vertebrate animals include the following: They have/are

i) Head with brain and skull
ii) Vertebral column – during development in most (all but Myxini), surrounding and ultimate replacement of notochord by bony or bone-like, hollow vertebrae; also, encase brain in protective box (skull or cranium) of bone or cartilage
iii). Neural crest ectoderm – a unique set of stem cells that form near neural tube and migrate during development, involved in forming a variety of structures.
iv) Highly developed internal organs such as unique kidney and excretory system**,** endocrine glands (make many hormones) and specialized heart; closed circulatory system
v) Endoskeleton made of cartilage and/or bone

9.2.2.1 Classification of Vertebrates

Sub phylum vertebrata are diverse, there are about 53, 000 living vertebrates. They are divided into two super classes and 9 classes as following:

Superclass Agnatha (jawless fish)

Class Myxini – hagfish

Class Pteraspidomorphi – lampreys

Superclass Gnathostomata (jawed vertebrates)

Class Chondrichthyes: cartilaginous fishes

Class Sarcopterygii:sarcopterygians or fleshy-finned fishes

Class Actinopterygii: ray-finned fishes

Class Amphibia – frogs, salamanders, caecilians

Class Reptilia – turtles, tuatara, lizard. Snake, crocodiles

Class Aves – birds

Class- Mammalia

Activities

1. State at least three major characteristic features of Gnathostomes.

2. What is the distinguishing feature of each of the fish classes?

3. Why are you not likely to see members of the super class Agnathans around your area?

4. Collect a fish from the aquarium or lake and attempt to classify as either

Class Amphibia

Amphibians are cold blooded animal with moist, hairless skin through which water can pass in and out. Nearly all amphibians live the first part of their lives in water and the second part on

Land-a double life reflected in the name *amphibian*, which comes from the Greek words *amphi*, meaning “both,” and *bios*, meaning “life.” Amphibians were the first animals with backbone to adapt to life on land. They are the ancestors of reptiles, which in turn gave rise to mammals and birds.

Scientists recognize more than 5,000 species of amphibians, all of which are members of one of three main groups: frogs and toads, salamanders, or caecilians. Frogs and toads are the most abundant of all amphibians, numbering more than 4,000 species. Frogs have smooth skin and long limbs. Toads, in contrast, have warty skin and short limbs.

Amphibians' adaptations to live on land:

- **Legs.** Some ancestral fish undoubtedly lived in shallow freshwater marshes and lagoons where they could find more food and deposit eggs "out of reach" of larger aquatic predators. For a fish even partially out of water, buoyancy would be diminished and more muscular and leg like fins would have been an enormous advantage.
- **Cutaneous respiration and lungs.** Extended visits to land would have been problematic for fish that extract oxygen from water moving through gill slits, and this selected for fish that could absorb more oxygen directly through their skin. Gulping air into pouches in the gut was another solution and these pouches eventually evolved into lungs.
- **Improved vascular system.** Larger muscles require more oxygen, and the heart and circulatory system allowed greater oxygen transport between the respiratory tissue and the body.

Activity: What adaptations allowed amphibians to move out of water?

There are three orders of amphibians:

a) **Salamanders and newts (Order Caudata-Urodela)**

-This group includes salamanders, newts and mudpuppies. The term caudata is derived from the Latin for tail, making this group (roughly) the "tailed-amphibians". They typically have slender bodies with long tails, and arms and legs of equal size.

- Urodelas are usually found in or near water and often reside in moist soil under rocks or logs. ---The adults usually spend most of their time on land and have a diet consisting of insects and worms and burrow in mud at the bottom of marshes

Frogs and toads (Order Anura)- Members of this order have the following characteristics:

-"Anura" comes from the Greek words meaning no tail, making these the "tail-less amphibians". Since their skin absorbs oxygen most efficiently when damp and tends to lose water rapidly, remaining near water is necessary for most frogs (and salamanders). As a defense mechanism some frogs (e.g., poison arrow frogs) secrete potent toxins into the mucus layer of their skin.

-Hind legs are longer than front limbs; and by this they are well adapted for hopping, jumping and swimming.

- Live in aquatic environment, although some are well adapted to drier habitats.

- Larval forms are called tadpoles lacking true teeth, are usually herbivorous, and develop hind limbs before front limbs (which is the opposite of Urodela larvae).

- Larvae also lack external gills, having opercular chambers that allow water to flow over internal gills, before exiting through a spiracle.

c) Order Gymnophiona (Caecilians). They have the following features:

-Lack legs (dig by ramming its bony head through the soft dirt)

-Members of this order are blind and legless amphibians that are shaped like worms. They burrow in moist soil in tropical habitats of Africa and South America, feeding on soil invertebrates such as worms and insects. Some caecilians live in moist soil that is rich in decayed plant matter.

Class Reptilia

There are about 6,550 living species of reptiles worldwide. Reptiles live in a wide range of habitats, including forests, swamps, grasslands, deserts, oceans, and mountains. The name "reptile" is generally applied to any of a group of ectodermic (cold-blooded i.e. need an "outside" source of heat to generate adequate body heat) vertebrates in the Class Reptilian. Reptiles must regulate their body temperature by behavior, either by basking in the sun to keep warm or by hiding under cover to keep cool. Reptiles have dry and not slimy skin. They are covered in scales or a shell. If they have legs, they have claws on their toes. Reptiles can be far from water sources because their skins retain water better than that of amphibians. Reptiles lay amniotic eggs that have a leathery shell preventing rapid water loss. Reptiles were the first animals to fully escape a dependence upon the availability of an open body of water. What adaptations were required for this transition?

- ✓ Thick, dry skin with scales, which was less prone to desiccation (water loss).
- ✓ Amniotic eggs were one of the most important evolutionary innovations.

Structures of amniotic egg:

• Air cell: located in the large end of the egg.

• Yolk: the principal nutritional source for the embryo.

• Albumen: clear, cushioning protein surrounding the yolk.

• Chalazae: whitish cord-like proteins that support the yolk in the center of the albumen.

• Shell membranes: there are two of these surrounding the albumin.

• Shell: is composed mainly of protein embedded with calcium carbonate. If the hen lays brown

eggs, the brown pigments are added to the shell in the last hours of shell formation. The shell contains several thousand pores that permit the egg to "breathe

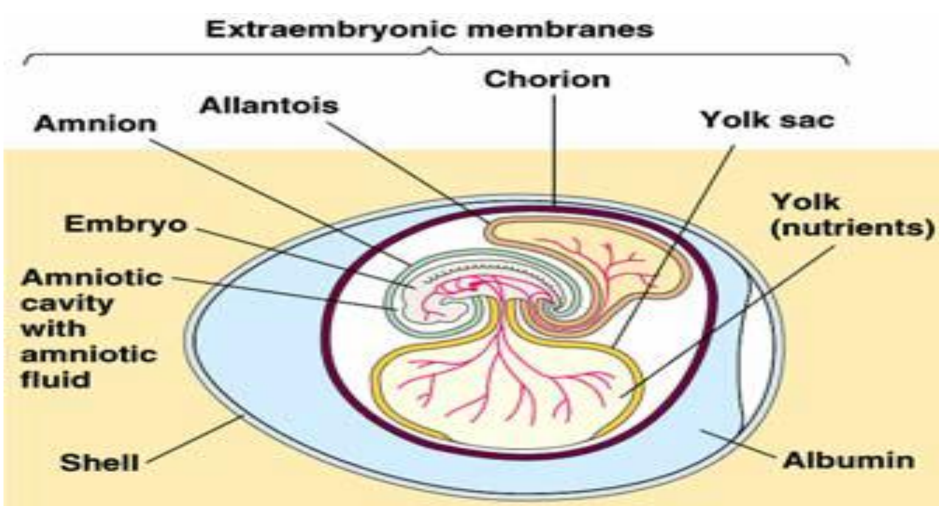


Figure 9.5 amniotic egg

- ✓ **Internal fertilization.** A shelled egg layed on dry land can no longer be fertilized by sperm swimming freely in water. Internal fertilization allows sperm to swim to the eggs in the moist interior of the female's body, and for fertilization to occur before the hard shell is added around the egg.

- ✓ **Breathing.** Muscles of the rib cage expand and contract to pump larger quantities of air into larger, more advanced lungs.

Classification of reptiles is still being resolved, and zoologists have been revising the various classifications of reptiles. There are three important groups that we will consider here:

Turtles and Tortoises (Order Chelonia): among which the body is surrounded by a protective shell.

Lizards and Snakes (Order Squamata): Snakes evolved from a legged lizard, and some still possess vestigial leg bones.

Crocodiles and Alligators (Order Crocodylia): In several ways crocodiles more closely resemble birds than other reptiles, such as in building nests and caring for their young. Possibly there was a close relationship among the dinosaur ancestors from which crocodiles and birds descended.

> **Activity**: Explain how the adaptations of early reptiles enabled these animals to live on land?

Birds (Class Aves)

Birds are the direct descendents of theropod type dinosaurs, and certain key traits of birds can be linked to anatomical features of these dinosaurs:

• **Feathers** are composed of the same material (keratin protein) as the scales of reptiles. They provide efficient insulation to both hot and cold environments and form an aerodynamic surface necessary for flight.

• **Bones and skeleton adapted for flight.** If you have ever carved a turkey, you have encountered the fused collarbone called the **furcula** (or the 'wish bone') and a large sternum bone called the **'keel'** to which the large flight muscles are attached. The bones are said to be pneumatic (filled with air spaces) to reduce weight, and these air spaces participate in respiratory oxygen storage.

• **Endothermy** or being ‘warm-blooded’. Unlike modern reptiles, birds can generate enough heat internally to regulate and maintain a constant body temperature, thus allowing birds to inhabit habitats (think of penguins) unacceptably cold for reptiles. There is some evidence that this trait evolved among the theropod ancestors of birds.

For terrestrial vertebrates the greatest numbers of species are found among the birds. Some familiar birds are representatives of the major Orders, such as: Eagles and hawks, Hummingbirds, Owls, Penguins, Pigeons, Parrots, Songbirds (robins, warblers, orioles, etc)**,** Woodpecker.

Activity: Why do you think that some birds are not able to fly even if they have wings? Describe it.

Mammals (Class Mammalia)

Although mammals appear to have evolved early during the Mesozoic (even before birds), they did not rise to predominance until the ecological niches become vacant with the demise of the dinosaurs.

Activities

1. Describe the characteristic features of mammals
2. Distinguish mammals from other vertebrates

General Characteristics of mammals

• Hair, like feathers of birds evolved from the scales of a reptilian ancestor and are composed of similar proteins. Endothermy, and insulation provided by hair, allowed mammals to be active at night and survive even bitter arctic winters.

• Mammary Glands, which secrete milk, assured a food supply during the precarious early life of the newborn.

• Internal fetal development. Among placental mammals (the most common type) the circulatory system of the fetus and mother become intimately intertwined within a placenta, where exchange of nutrients and waste products can occur. This allows long-term internal development of the fetus.

- A single jaw bone on either side. In all other vertebrates, there is more than one bone on each side of the jaw.
- Four chambered heart with the main artery leaving the heart curves to the left becoming the aortic arch. (In birds it curves to the right and in all other vertebrates there is more than one main artery leaving the heart)
- Muscular diaphragm separates the thoracic cavity from the abdominal cavity.

Classifications of Mammals-there are three subclasses of mammals:
Infraclass Eutheria: (placentals)

This group of mammals, also known as the placental is characterized by having:- A placenta - a reproductive structure, which is housed in the uterus of the female by which the developing embryo connects to the mother to get nutritive support. The offspring of eutherians receives all its nutritional needs through the placenta that links it to the mother to develop into a fully developed organism before birth. The period of development (gestation period) varies with the species of mammal but undoubtedly longer than that in the metatherians that we have just described above. For example the gestation period in the whales is 2 years, in mouse 21 days, and in humans the period is 9 months. These mammals are the most abundant and diverse of the class representing 94% of the species of mammals.

Infraclass Metatheria (Marsupiala) marsupials - kankaroo, opossum, and koala
Marsupials (e.g., kangeroos) are less common and predominate in Australia, although some (e.g., the opossum) occur in other regions. The fetus of marsupials develops in an external pouch of the mother. Members include the kangaroos, Opossums, and koalas.

- ❖ Monotremes (e.g., the platypus) have retained the ancestral characteristic of laying eggs.

Activity:

Why a young marsupial mammal such as kangaroo enters to abdominal pouch after birth?

Unit 10

Applications of Biological Sciences

Learning Objectives: This is chapter highlights the major areas of application of biology to human and the environment. Thus, at the end of this chapter students are expected to

- ✓ List the different areas where biological knowledge can be applied
- ✓ Describe and understand the application of biological sciences in the different areas/sectors
- ✓ Understand the application of biology in forensic science and warfare

Self-test

1. Describe the application of biology in different areas such as medicine, Environmental engineering, Biosystem engineering, Chemical engineering, Biosensor technology, industries (like Food, brewery, pharmaceutical, tannery and textile) and agriculture etc.

2. Discuss the role of biological knowledge in forensic science and warfare

10.1 Application of Biology in medicine and other health sciences (Fast diagnosis tools, drug and vaccine production, gene therapy, immuno-diagnosis, immunotherapy, transplantation, medicinal plants, etc)

Biotechnology contributes much towards the growing public and global health needs. It has revolutionized mankind since its existence. It provides effective diagnostics, prevention and treatment measures including production of novel drugs and recombinant vaccines. It gives effective drug delivery approaches, new methods for therapeutics, nutritionally enriched genetically modified crops and efficient methods for environmental cleanup. Accordingly, life quality and expectancy have been increased worldwide through the services provided by biotechnology.

Parasitic and infectious diseases like Acquired Immunodeficiency Syndrome (AIDS) and tuberculosis (TB) have been diagnosed rapidly at relatively low cost. Molecular diagnostic tools including polymerase chain reaction (PCR), recombinant antigens and monoclonal antibodies have been used for this purpose. Biotechnology has also offered modern diagnostic test kits, rickettsial, bacterial and viral vaccines along with radiolabelled biological therapeutics for imaging and analysis. Vaccination by making recombinant vaccines has the potential to eradicate non-communicable diseases like cancer. Naked DNA vaccines, viral vector vaccines and plant-derived vaccines are found to be most effective against a number of bacterial and viral diseases.

Other biological offer to health science is transplantation technology**.** It is the process of moving cells, tissues or organs (called transplant, graft or organ transplant) from one site of the body to another(within or between individuals) for the purpose of replacing or repairing damaged or diseased organs and tissues. This is analogous to spare parts in machines.

For example, extremely thin pieces of skin could be cut free and would obtain enough nourishment from the serum in the graft bed to stay alive while new blood vessels are being formed. This free grafting of skin, together with the flap techniques constituted the main therapeutic devices of the plastic surgeon in the correction of various types of defects. Skilled manipulations of such grafts produced surprising improvements in the appearance of those born with malformed faces and in the disfigurements resulting from severe burns. Cornea, which structurally is a modified form of transparent skin, can also be free grafted, and corneal grafts have restored sight to countless blind eyes.

It is extremely important that the malfunction of an organ system can be corrected with transplantation of an organ (eg, kidney, liver, heart, lung, or pancreas) from a donor. However, the immune system remains the most formidable barrier to transplantation as a routine medical treatment. The immune system has developed elaborate and effective mechanisms to combat foreign agents. These mechanisms are also involved in the rejection of transplanted organs, which are recognized as foreign by the recipient's immune system. Understanding these mechanisms is important, as it aids in understanding the clinical features of rejection and, hence, in making an early diagnosis and delivering appropriate treatment. Knowledge of these mechanisms is also critical in developing strategies to minimize rejection and in developing new drugs and treatments that blunt the effects of the immune system on transplanted organs, thereby ensuring longer survival of these organs

Plants have been used as medicine since time immemorial. The FAO estimated in 2002 that over 50,000 medicinal plants are used across the world. The WHO estimates that some 80% of the world's population depends mainly on traditional medicine primarily of plants origin. For standard production and utilization, WHO formulated a policy on traditional medicine in 1991, and since then has published guidelines for them, with a series of monographs on widely used herbal medicines.

Medicinal plants may provide three main kinds of benefit: health benefits to the people who consume them as medicines; financial benefits to people who harvest, process, and distribute them for sale; and society-wide benefits, such as job opportunities, taxation income, and a healthier labour force. However, development of plants or extracts having potential medicinal uses is blunted by weak scientific evidence, poor practices in the process of drug development, and insufficient financing. Traditional healers, Biologist, chemical engineers and health professionals are highly responsible to advance such huge opportunity.

10.2 The application of Biology in technology

Biological engineering, or **bioengineering/bio-engineering**, is the application of principles of biology and the tools of engineering to create usable, tangible, economically viable products. Biological engineering employs knowledge and expertise from a number of pure and applied sciences such as mass and heat transfer, kinetics, biocatalysts, biomechanics, bioinformatics, separation and purification processes, bioreactor design, surface science, fluid mechanics, and polymer science. It is used in the design of medical devices, diagnostic equipment, biocompatible materials, renewable bioenergy, ecological engineering, agricultural engineering, and other areas that improve the living standards of societies. Examples of bioengineering area include bacteria engineered to produce chemicals, new medical imaging technology, portable and rapid disease diagnostic devices, prosthetics, biopharmaceuticals, and tissue-engineered organs. Bioengineering overlaps substantially with biotechnology and the biomedical sciences in a way analogous to how various other forms of engineering and technology relate to various other sciences.

Bioengineers can apply their expertise to other applications of engineering and biotechnology, including genetic modification of plants and microorganisms, bioprocess engineering, and biocatalysis. Working with doctors, clinicians and researchers, bioengineers use traditional engineering principles and techniques and apply them to real-world biological and medical problems.

10.3 Application of Biology in agriculture (soil fertility, tissue culture, animal breeding and transgenic animals, plant disease and pest management)

Food supply for the fast growing population is mainly constrained by the loss of soil fertility and diseases of crops and animals. In addition, lack of advanced tool remains a problem. The multiple applications of biology in agriculture have substantially improved the production and supply of food for human as well as feed for animals. The following are some few examples on the advancements of agricultural production involving knowledge of biology and technology.

Soil fertility management practices using biological knowledge include the use of organic fertilizer, bio-fertilizers, crop rotation with legumes and the use of improved germplasm, combined with the knowledge on how to adapt these practices to local conditions.

Plants can be propagated quickly and in large quantity by tissue culture technique. The example is palm trees, orchids, bananas, and carrots. Using this technology large quantity of food with desired quality can be produced in reasonably little area. Genetic Engineering has produced seedless fruits such as watermelon, papaya, orange and grape. This will significantly reduce the crop cycle. Moreover, farmers used to plant crops traditionally using conventional tools. With the advancement of biology and technology, they now can plant crops in many different cultivation ground along with more efficient cultivation methods.

Animal breeding addresses the genetic value of livestock. Selecting for breeding animals with superior traits in growth rate, egg, meat, milk, or wool production, or with other desirable traits has revolutionized livestock production throughout the entire world. Animals can also be genetically modified (transgenic animals) for valuable traits. There are many potential applications of transgenic methodology to develop new and improved strains of livestock. Practical applications of transgenics in livestock production include enhanced prolificacy and reproductive performance, increased feed utilization and growth rate, improved carcass composition, improved milk production and/or composition, modification of hair or fiber, and increased disease resistance. Development of transgenic farm animals will allow more flexibility in direct genetic manipulation of livestock. Gene transfer is a relatively rapid way of altering the genome of domestic livestock. The use of these tools will have a great impact toward improving the efficiency of livestock production and animal agriculture in a timely and more cost-effective manner. With ever-increasing world population and changing climate conditions, such effective means of increasing food production are promising.

Applications of animals in research are also another area of animal biotechnology. Biomedical research involving the use of animals has been the cornerstone of medical progress for the past several centuries, but ethical concerns about the use of vertebrates, which are more commonly understood to be sentient animals, have led researchers, veterinarians, and others in laboratory animal science to search for alternatives. Hence invertebrates can serve as replacements for their vertebrate counterparts in many areas of research, testing, and education as shown in Table below.

Table 10.1. Selected invertebrate used in developmental biology, diseases and genetic models

Model	Species used
Bone morphogenic proteins	*Drosophila*
Calcium signaling	*Asterina pectinifera*
Cilia regulation of development pathways	*Caenorhabditis elegans*
Chromatin insulators	*Drosophila*
Developmental glycobiology	*Drosophila*
Formation of the nervous system	*Drosophila*
Gene regulatory network	*Echinoidea*
MicroRNA function in embryogenesis	*C. elegans*
Pattern signaling and retinal development	*Drosophila*
Pituitary patterning	*Drosophila*
Regulatory switches	*Drosophila*
Semophorin in developing nervous system	Caelifera (grasshopper)
Tubulogenesis	*Drosophila*
Nitrous oxide signaling during neural development	*Locusta*, *Schistocerca*, *Acheta*, *Manduca*, *Drosophila*
Aging	Bivalves, *Drosophila*, *Caenorhabditis elegans*, *Macrostomum lignano* (flatworm)

Hypoxia	*Drosophila*, *Daphnia magna*, *C. elegans*
Freeze tolerance	Various species of insects
Wound healing	*Hirudo medicinalis*, *Drosophila*, *C. elegans*
Sleep regulation	*Drosophila*
Stem cell roles in cancer	*Drosophila*, *C. elegans*
Epilepsy	*Drosophila*, *C. elegans*
Mitochondria-associated diseases	*C. elegans*
Gene regulation	*C. elegans*, *Drosophila*

Pests and diseases are severe challenges for crop production. Disease in crops is adversely reducing quantity or quality of yield. Organisms that cause infectious disease in crops include fungi, oomycetes, bacteria, viruses, viroids, virus-like organisms, phytoplasmas, protozoa, nematodes and parasitic plants. Different biocontrol methods are developed to combat these diseases. Pests can also be controlled using integrated biological knowledge as described below.

Pest control:

Pest control is one of the primary applications of biology in agriculture. Biological knowledge has developed a method to suppress or control the population of undesirable insects, other animals or plants. This is done by introducing, stimulating or artificially raising their natural enemies to economically unimportant levels. Among the mechanisms used are natural ones, such as predation, parasitism or herbivory.

Creation of plants resistant to pests:

Another application of biology in agriculture is the development of plant varieties resistant to pests. Around the world, unwanted animals are a threat to agricultural crops. These significantly reduce yield and affect almost every aspect of the plants. Through conventional breeding, some insect resistant crops have been created. Recently there have been great advances in biotechnology. For example, resistance to pests and diseases of crops has increased through genetically modified plants, which implies the reduction of chemical control of pests.

Selective breeding to improve agricultural plants and animals:

Since the 18th century, knowledge about biology has been used to carry out crossings of related species. Selective breeding seeks to improve traits such as taste, color, disease resistance and productivity. At the beginning of the 20th century, genetics began to be used to develop new varieties of plants and animals. This has brought important changes in agriculture, especially in the productivity of some crops.

Understanding the effects of climate on crops:

Biology help understand how climate change affect crops. For example, temperature plays an important role in the different biological processes that are critical for the development of the plant. The optimum temperature varies for germination, growth and reproduction. These optimum temperatures must occur at certain times in the life cycle of the plant; otherwise, the growth and development of the plant may be affected.

In addition, through the development of biotechnology and molecular biology, plant has been genetically engineered to produce their own pesticide. So they no longer need to be spayed manually. Among those plants are apples, pear, cabbage, broccoli, and potatoes.

10.4 Application of Biology in industries (Food, brewery, pharmaceuticals, tannery and textile, single cell production, preservation)

Industrial biotechnology, also known as white biotechnology, is the modern use and application of biotechnology for the sustainable production and processing of bioproducts such as food substances, chemicals, bio-materials and fuels from renewable sources, using living cells and/or their enzymes. Primarily, the enormous capability of microorganisms and their enzymes are utilized for the production of food supplements such as vitamin B2, many other pharmaceuticals such as drugs and vaccines, bioplastics such as polylactic acid, energy carriers such as biogas and bioethanol, detergents, pulp and paper, quality textiles fibers, and many agricultural products. Most importantly, single cell proteins (SCP) can be produced from wide range of microorganisms. Best examples are mushroom, spirulina, yeast, green algae. SCP technology is a promising area in alleviating food security in ever growing population.

Food preservation is another area of industrial biotechnology which if the processes to stop food spoilage due to microbial action. The biological methods of food preservation have become increasingly important. These consist of adding cultures of innocuous microorganisms of high purity to the food. The cultures have an inhibitory effect on the undesirable decomposition microorganisms

10.5 Application of Biology in waste treatments and recycling (Bioenergy, bioremediation, water treatment, biomining)

Biotechnological processes are used for wastewater treatment and reuse. This area coordinates engineers, biologists, chemists. Appropriately designed waste management system can be utilized to remove hazardous wastes from the environment and for the production of renewable energy such as bio-fuels and hydrogen. Particularly, for preventing environmental pollution through environmental engineering, activated sludge process, trickling filters, biotrickling filters, oxidation ponds, anaerobic treatment, composting units and biogas reactors are used extensively among the waste treatment technologies. Bio-mining is also one area of interest where chemical mining is substituted by microorganisms that can efficiently extract minerals from natural ores. Note that chemical mining generates many pollutants in the environment.

10.6 Application of Biology in forensic Science

Forensic biologists inspect crime scenes for potential sources of evidence such as blood, saliva, and hair, and then they analyze the specimens in a laboratory, focusing on DNA analysis. Additionally, fingerprints are also important to investigate crime and the paternity case of a child; this is because each individual has unique fingerprints that do not change throughout life. Based on their investigations, forensic biologists write up their findings in technical reports and are called upon to testify in court. Finally, this data is used to investigate the related transgression, and then these facts are put forward in the court that’s quite helpful in order to castigate the criminal. These days 'bioinformatics is widely acceptable in the field of forensic science because, with the help of computational tools, it became quite uncomplicated and reliable to gather evidence regarding a particular crime scene.

10.7 Biological warfare

Self-Test

1. What is biological warfare?

2. Do you know the reason why the use of biological warfare is not allowed?

Biological warfare (BW) also known as germ warfare is the use of biological toxins or infectious agents such as bacteria, viruses, and fungi with the intent to kill or incapacitate humans, animals or plants as an act of war.

Biological weapons include any microorganism (such as bacteria, viruses, or fungi) or toxin (poisonous compounds produced by microorganisms) found in nature that can be used to kill or injure people. The act of bioterrorism can range from a simple hoax to the actual use of these biological weapons, also referred to as agents. A number of nations have or are seeking to acquire biological warfare agents, and there are concerns that terrorist groups or individuals may acquire the technologies and expertise to use these destructive agents. Biological agents may be used for an isolated assassination, as well as to cause incapacitation or death to thousands. If the environment is contaminated, a long-term threat to the population could be created.

Activities

1. *Describe the principles behind gene therapy, immuno-diagnosis and immunotherapy*
2. *Discuss the principles behind transplantation incompatibility*
3. *What is the difference between antibiotics and vaccines in combating diseases?*
4. *Outline how insulin is produces at large scale*
5. *How do you advice the Ethiopian government to include single cell protein technology in food security program*
6. *Study a typical solid waste or waste water treatment system and describe the major phases and their purposes*
7. *Have you ever heard the term "Bacterial Cement" what is it and how and where it is applied?*
8. How can fingerprints, hair and fibers, and blood evidence be used to solve a crime?
9. *Can you mention other practical application of forensic science?*
10. *Why biological warfare is more dangerous than other warfare?*