27 BIOCHEMISTRY

Student Learning Outcomes [C-12-D-116 to C-12-D-139]

- Explain the basis of classification and structure-function relationship of carbohydrates.
- Explain the role of various carbohydrates in health and diseases.
- Identify the nutritional importance of carbohydrates and their role as energy storage.
- Explain the basis of classification and structure-function relationship of proteins.
- Describe the role of various proteins in maintaining body functions and their nutritional importance.
- Describe the role of enzyme as biocatalyst and relate this role to various functions such as digestion of food.
- Identify factors that affect enzyme activity such as the effect of temperature and pH.
- Explain the role of inhibitors of enzyme catalyzed reactions.
- Describe the basis of classification and structure-function relationship of lipids.
- Identify the nutritional and biological importance of lipids.
- Identify the structural components of DNA and RNA.
- Differentiate between the structures of DNA polymer (double strand) and RNA (single strand).
- Relate DNA sequences to its function as storage of genetic information.
- Relate RNA sequence (transcript) to its role in transfer of information to protein (translation).
- Identify the sources of minerals such as iron, calcium, phosphorus and zinc.
- Describe the role of iron, calcium, phosphorous and zinc in nutrition.
- Explain why animals and humans have large glycogen deposits for sustainable muscular activities. Hibernating animals (polar bear, reptiles and amphibians) accumulate fat to meet energy resources during hibernation.
- Identify complex carbohydrates which provide lubrication to the elbow and knee.
- Describe fibrous proteins from hair and silk.
- Explain how cholesterol and amino acid serve as hormones.
- Identify insulin as a protein hormone whose deficiency leads to diabetes mellitus.
- Explain the role of minerals in structure and function.
- Identify calcium as a requirement for coagulation.
- Identify how milk proteins can be precipitated by lowering the pH using lemon juice.

Biochemistry is the branch of science that deals with the study of chemical substances found in living organisms and the reactions they undergo. The biological compounds are complex molecules with the same types of functional groups those found in simple organic compounds, such as alcohol, amine, aldehyde, ketone, carboxylic acid, ester, and amide groups.

This chapter focuses on the essential biomolecules such as carbohydrates, proteins, lipids, and nucleic acids, featuring their structures, functions, and roles in cellular processes. In addition to these biomolecules, the roles of minerals and enzymes in biochemical processes will also be discussed.

27.1 CARBOHYDRATES

Carbohydrates are naturally occurring organic compounds including sugars, starch, cellulose, and substances found in bacterial cell walls and insect exoskeletons. These act as major sources of energy in our diet. All carbohydrates are hydrates of carbon. Chemically, they are polyhydroxy aldehydes or ketones or their derived compounds.

1. **Monosaccharides** are the simplest carbohydrates commonly known as sugars, e.g. glucose and sucrose. They cannot be hydrolysed further into simpler compounds. The general formula of monosaccharides is $C_n(H_2O)_y$, where n ranges from three to seven. A monosaccharide with three carbon atoms is a triose, one with four carbon atoms is a tetrose; a pentose has five carbons, and a hexose contains six carbons, etc. They are also classified according to the functional group present, such as a ketose or aldose containing ketonic and aldehydic group, respectively. Glucose is an aldose whereas fructose is a ketose.

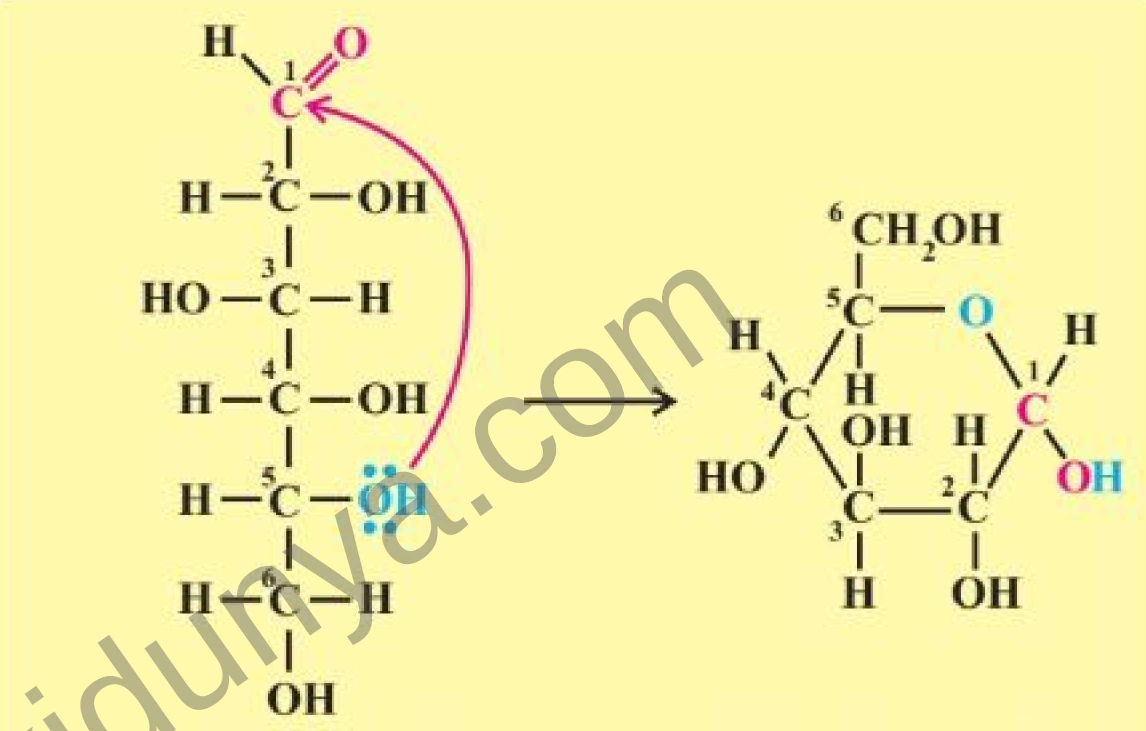


Figure 27.1 Linear and cyclic structures of glucose

Monosaccharides exist either as open chains or ring-shaped molecules. Sugars with five carbon atoms (pentoses) or six carbon atoms (hexoses) are more stable and hence more abundant as cyclic structures than as open chain structures. In their solid form, they exist in ring form and in solutions, their molecules exist as linear structures. For example, fructose forms a five-membered ring known as furanose, whereas glucose has a six-membered ring known as pyranose. The linear chain and cyclic structures are interconvertible. The cyclisation of glucose from its linear structure is shown in **Figure 27.1**.

The presence of many hydroxyl groups (–OH) in the sugar molecules results in the extensive hydrogen bonding between their molecules. For this reason, monosaccharides exist in solid form in their pure form. In their solutions, they form extensive


Fructose and glucose are present in honey in high concentrations. The thickness and viscosity of honey is due to their strong and intensive hydrogen bonding.

hydrogen bonding with water molecules, making them highly soluble in water. Monosaccharides are excellent source of instant energy in the living organisms. Glucose is called blood sugar due to its presence in the human blood, while fructose is abundant in fruits and honey.

2. Disaccharides

Disaccharides consist of two monosaccharide units joined together via glycosidic linkage, generally with the formula $C_{12}H_{22}O_{11}$. Among the most common disaccharides are sucrose, lactose and maltose. They are formed through a condensation reaction, when the hydroxyl group of one monosaccharide combines with the hydrogen of another monosaccharide through a covalent bond, releasing a molecule of water. The bond C – O –C is known as the glycosidic bond. For example, sucrose which is a common table sugar, is a disaccharide of glucose and fructose as given in **Figure 27.2.**

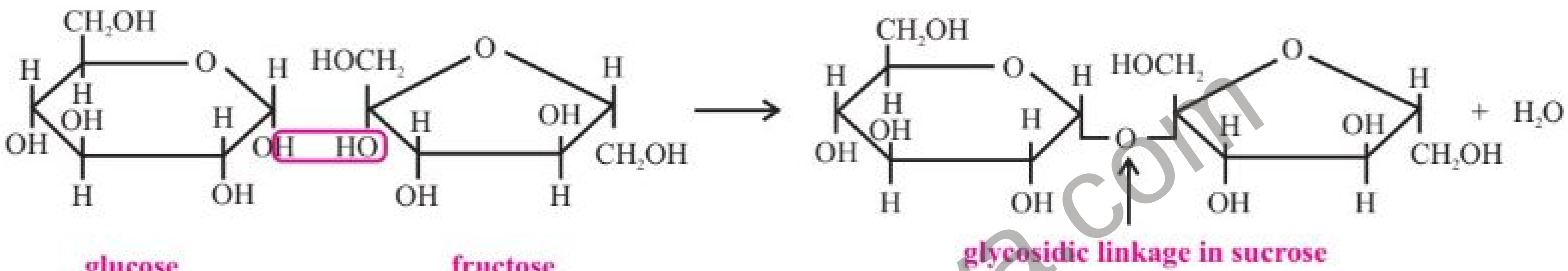


Figure 27.2 **Formation of the Sucrose molecule**

3. Polysaccharides

Polysaccharides are large molecules consisting of a large number of monosaccharide units joined together. They have high molecular mass, having general molecular formula, $(C_6H_{10}O_5)_n$. Polysaccharides give simple sugars, i.e., monosaccharides on hydrolysis. Common examples are starch, glycogen, cellulose and pectin. Starch is the main storage of energy in plants, and consist of glucose units. It has two components, amylose and amylopectin.

Amylose has a long, unbranched chains with many glycosidic linkages. While amylopectin is a compact highly branched structure consisting of many glucose units **(Figure 27.3)**. Amylopectin is soluble in water, while amylose is insoluble. Potato, sugar beet, rice, and grains have large quantities of starch in them.

Cellulose is the major structural material found in plant cell walls. It consists of glucose units (up to 2500) to form long unbranched chains linked by glycosidic bonds **(Figure 27.3)**. These chains form strong hydrogen bonds with each other, making cellulose rigid and insoluble in water. It makes most of the plant leaves, branches, and trunk. It is very important in human food in the form of fibre, which improves the gut health. **Glycogen,** or animal starch, is a polymer of glucose that is stored in the liver and muscles of animals. It is also called the 'animal starch'. The structure of glycogen is very similar to that of amylopectin, but it is more highly branched, making it different from starch. However, there is no amylopectin structure in glycogen.

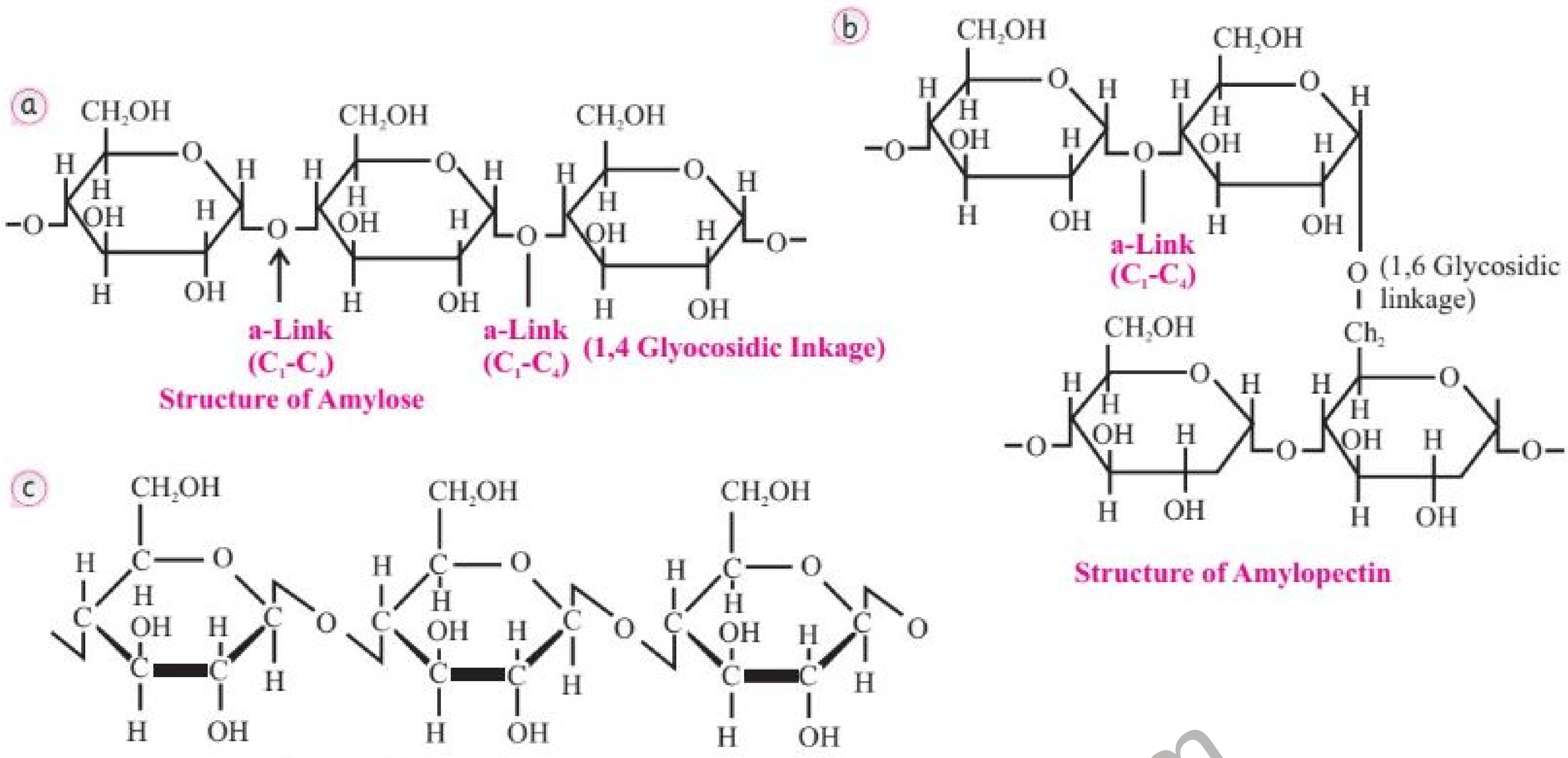


Figure 27.3 Structure of a) amylose, b) amylopectin in starch, and c) cellulose

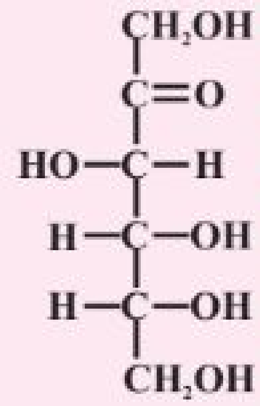
27.1.1 Nutritional Importance of Carbohydrates

Carbohydrates have a complex role in the human health. Although, they are essential for energy and nutrient intake, the type and amount consumed have a major effect on health. By selecting the right carbohydrates and balanced intake, we can reduce the risk of diseases. The following are important physiological functions of carbohydrates and the risk of imbalance in their intake.

1. Simple sugars like glucose are the primary source of energy for cells. They are easily absorbed and metabolized to release energy, with 1 g of glucose providing about 15.6 kJ. Excess glucose is stored as glycogen in the liver and muscles. Normally, blood glucose levels range between 70-110 mg/dL, though it may fluctuate slightly during the day. These levels are controlled by the hormones insulin and glucagon. If blood glucose levels rise above the normal range, it can lead to diabetes, a chronic condition that occurs when the pancreas does not produce enough insulin or when the body cannot effectively use the insulin it produces. Uncontrolled diabetes can cause hyperglycemia (high blood sugar), which, over time may damage body systems, particularly nerves and blood vessels. On the other hand, insufficient carbohydrate intake can result in fatigue and reduced physical and mental performance.
2. The main function of fructose is to provide energy during metabolism in the body. Its high intake causes obesity, resulting in an excessive accumulation of fat in the body. Diets high in refined sugars have been associated with a higher risk of chronic diseases such as diabetes, heart disease, and certain cancers. Conversely, complex carbohydrates and fibers are protective with multiple health benefits. When the body has sufficient carbohydrates for its energy needs, it utilizes these instead of breaking down proteins or fats for fuel and energy production.

Quick Check 27.1

a) The linear structure of fructose is given here.
   i. Show the conversion of this structure into the cyclic structure.
   ii. Predict whether fructose is soluble in water or not. Explain your reasoning.
   iii. Predict the physical state of fructose in its pure form by analyzing its structure.
b) What is glycosidic linkage? Show how it is formed between fructose and glucose.
c) Briefly describe any two functions of carbohydrates and how these functions are related to their molecular structures.



27.2 PROTEINS

Proteins are large, complex macromolecules found in all living organisms abundantly. Our skin, hair, haemoglobin in blood (red pigment), and muscles, all are proteins. Proteins play key roles in the human body from building the tissue structure to various functions of the body cells and organs. Any change in the structure or function of a protein may alter the body to behave abnormally.

When proteins are completely hydrolysed, they yield amino acids. About 20 different amino acids link together in various sequences to create a wide variety of proteins.

27.2.1 Structure-Based Classification

Proteins are linear chains of amino acids that are linked together by peptide bonds. A peptide bond is an amide bond that forms when the $-COO^-$ group of one amino acid reacts with the $-NH^{3+}$ group of the adjacent amino acid to form a linear polymer. The long chains of amino acids formed by many peptide linkages are called polypeptide chains. Each protein has specific polypeptide chains, which determine its structure and function.

To understand the complex function of a protein in an organism, it is necessary to determine the three- dimensional structure of its polypeptide chain. Proteins are organized into four structural levels: primary, secondary, tertiary, and quaternary.

Sickle cell anemia is a disease caused by the deformation of normal red blood cells to cells having sickle-like shape. This is caused by abnormal formation of haemoglobin. Sickle cells clog the blood veins and disrupt the normal blood circulation.

Primary structure: The primary structure of a protein is the specific linear sequence of amino acids linked by peptide bonds in a polypeptide chain. This sequence determines how the protein folds into its three-dimensional shape, which in turn defines its biological function. Even a small change in a single amino acid can alter the protein structure and impair its function. For example, proteins like albumin (with about 400 amino acids) and insulin rely on their precise amino acid sequences to function properly.

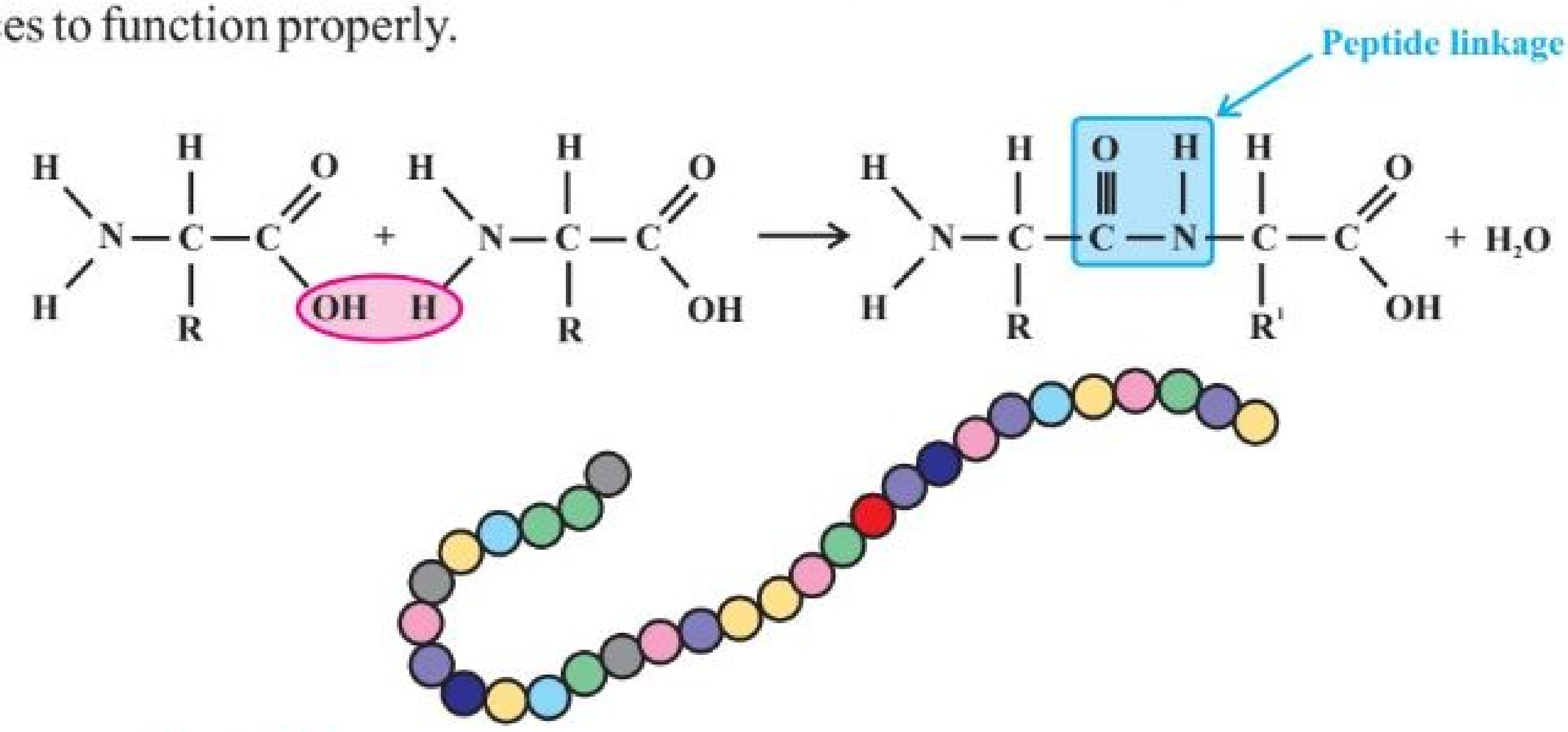


Figure 27.4 **The peptide chain formation by the peptide bonds between amino acids**

Secondary structure: The secondary structure of a protein arises when the backbone atoms form hydrogen bonds within a polypeptide chain, producing regular patterns such as α-helices and β-pleated sheets. In an α-helix, hydrogen bonds form along a single chain, creating a coiled, spiral structure (e.g., keratin). In contrast, β-pleated sheets form when hydrogen bonds occur between adjacent polypeptide strands, giving a folded, sheet-like structure (e.g., silk fibroin) as shown in **Figure 27.5**.

These structural arrangements provide stability and flexibility, contributing to the overall three-dimensional shape of a protein, which is essential for its specific biological function.

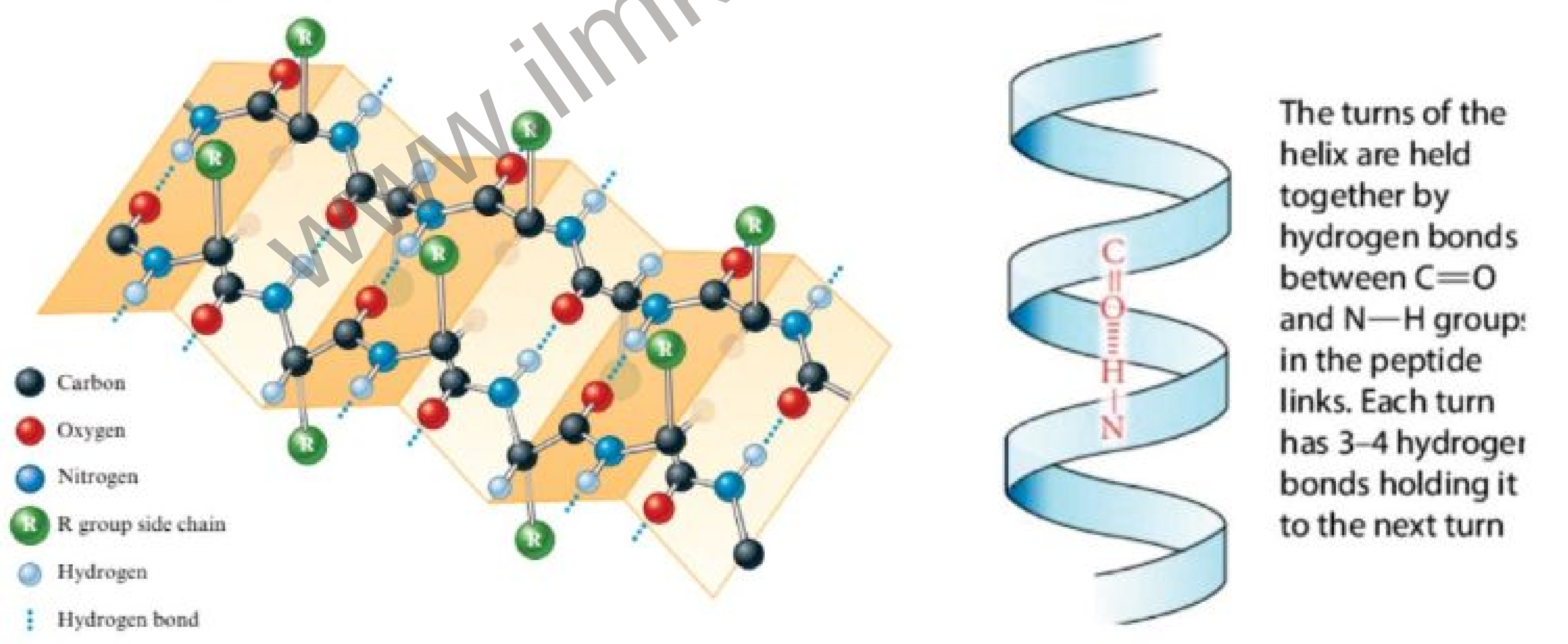
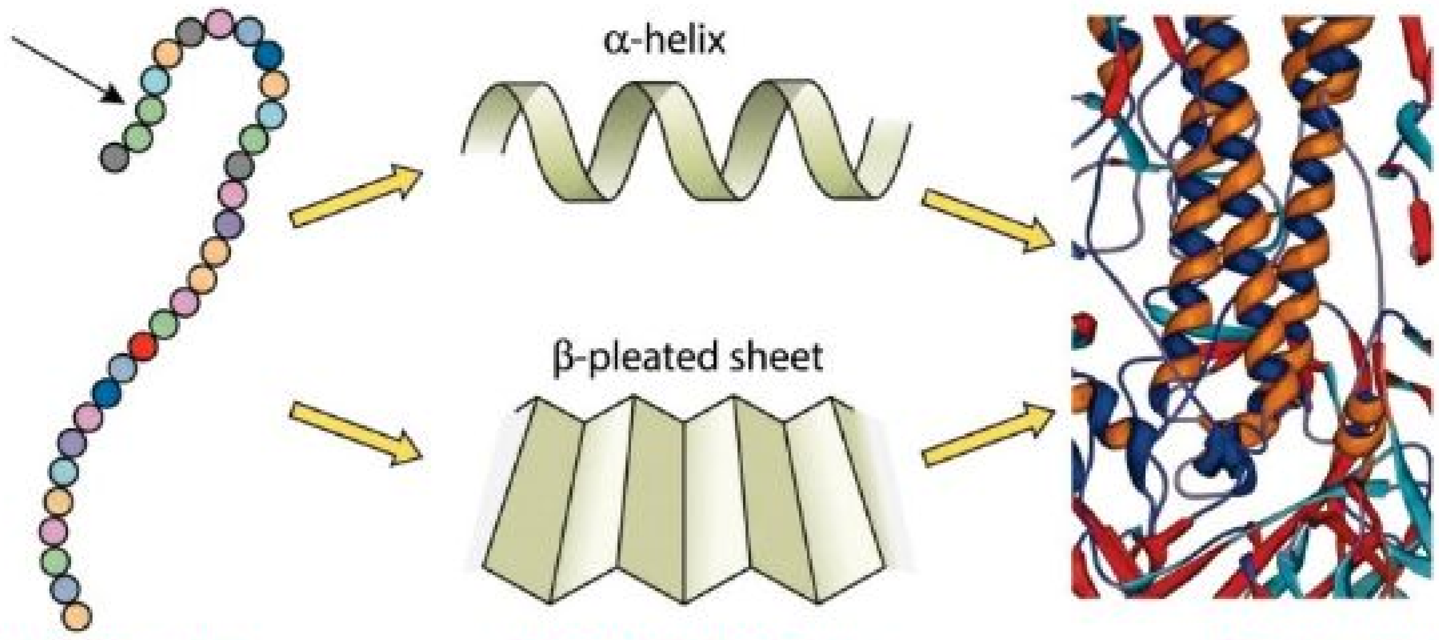


Figure 27.5 **Formation of α-helix and β pleated sheets from the primary amino acid chains**

Tertiary structure:

The tertiary structure of a protein is the overall three-dimensional shape formed when a polypeptide chain folds due to interactions between side chains (R-groups), including hydrogen bonds, ionic bonds, hydrophobic interactions, and disulphide bridges. These interactions cause the chain to twist and bend into a specific shape, often forming globular proteins. This three-dimensional structure determines the protein function. For example, in enzymes, the precise shape of the active site allows specific binding to the substrate, enabling catalytic activity. Any change in this structure can affect the enzyme activity.



Primary structure is the order in which the amino acids are linked in the chain

Secondary structure is the coiling or folding of the primary structure

Tertiary structure is the coiling or folding of the primary structure

Figure 27.6 From primary amino acid chains to tertiary structure of proteins

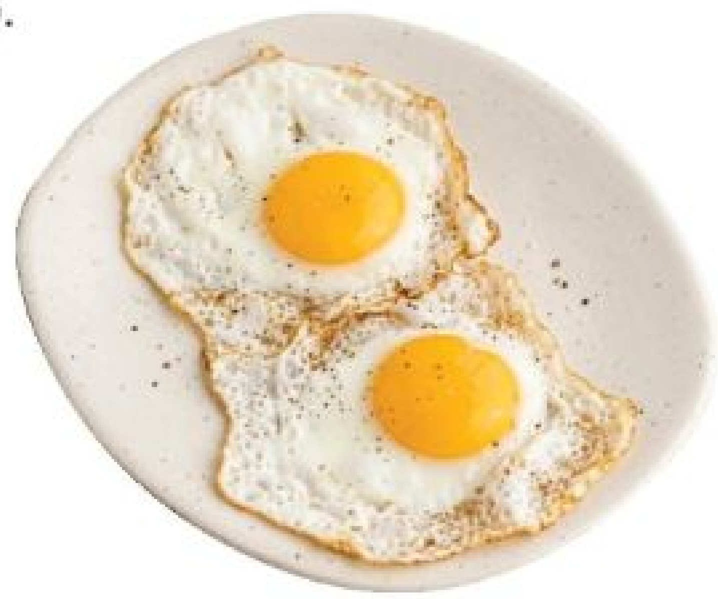
Keep in Mind

Some proteins have quaternary structures too. The quaternary structure arises when two or more folded polypeptide chains (subunits) associate by interactions such as hydrogen bonds, ionic (salt) bridges, hydrophobic interactions, and sometimes disulphide bonds.

Based on the overall shape of proteins which they take after tertiary or quaternary structure formation, they are divided into two main classes:

Fibrous Proteins: These proteins consist of long, rod-like, or thread-like molecules with polypeptide chains running parallel and linked by strong intermolecular hydrogen bonds or disulphide bonds to form fibres. These proteins are generally insoluble in water, mechanically strong, and stable. Therefore, they serve as the structural polymers. For example, collagen (connective tissue), keratin (hair, nails, skin), and myosin (muscle).

Globular Protein: If the shape of the whole protein molecule is spherical or ovoid, it is a globular protein. Most worker proteins (functional proteins), such as enzymes, hormones, and nutrients are globular proteins. Globular proteins are more sensitive to heat and pH. The white of an egg is hardened on heating as the hydrogen bonding between the chains is disrupted and the chains open up. Due to the same reason the milk protein casein is coagulated when the pH of the solution is changed by adding some lemon juice. This is called **denaturing of proteins**.



Egg white is a globular protein

27.2.2. Biological Functions of Proteins

Proteins can be grouped into different categories based on their biological and metabolic functions. There are some proteins which control or regulate specific physiological activities, such as growth, development, metabolism, and reproduction. These are called **Hormonal**

Proteins. An example is insulin, which is produced by pancreas in our bodies and is responsible for regulating the movement of glucose from the blood into cells.

Storage Proteins provide essential nutrients for the growth of the germinating seedlings or for the early development of animals. Ferritin is a storage protein found in some bacteria, and in plant and animal tissues, where it stores iron.

Structural Proteins are most abundant proteins in a vertebrate body. They are fibrous, or threadlike, which maintain the shape and give structural support, such as keratin in hair, fibrin in blood clots and collagen. They also forms the matrix of skin, ligaments, tendons, and bones.

Contractile Proteins, such as actin and myosin, make up the thin and thick filaments of a muscle involved in contraction and relaxation movement of the muscle fibre.

Defensive proteins help organisms to fight infection and prevent injury in the body. For example, antibodies recognize and bind to specific antigens (proteins present on pathogens) with high affinity, immediately destroying the antigens.

Transport or Carrier Proteins aid in the movement of molecules and ions across cell membranes. For example, iron atom attaches with oxygen atom through the hemoglobin molecules, as the blood travels between the lungs and the tissues.

Receptor Proteins are located within the cell's membrane and they receive chemical signals and responses from and to the cells.

Regulatory Proteins play a role in controlling cellular and physiological activities, such as insulin, which regulates sugar metabolism and growth hormone.

Quick Check 27.2

a) Keratin is a structural protein found in hair, nails, horn, hoofs, wool, feathers, enamel of teeth and outer layer of skin, where it gives strength and flexibility. It is not easily denatured. Which bond do you expect is responsible for this; hydrogen bond or disulphide bond? Explain.
b) How can two peptides with identical type and number of amino acids differ in their primary structure?
c) What are the two most common types of secondary protein structures in our body?
d) Why does a denatured protein no longer function properly?
e) The white of egg solidifies on heating. Explain why it happens.

27.3 ENZYMES AS BIOCATALYSTS

Enzymes are proteins that acts as biological catalysts needed for various chemical reactions that take place in living organisms. An enzyme speeds up a biochemical reaction to an extent that would be impossible without it. For example, one molecule of carbonic anhydrase in the blood can convert about one million of carbon dioxide and water molecules to carbonic acid in one minute.

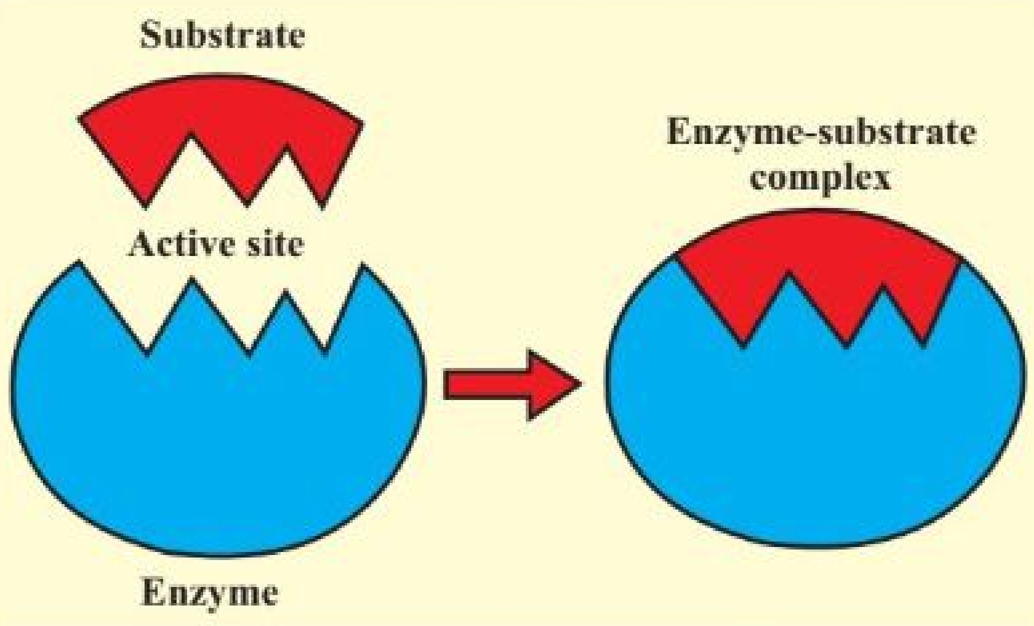


Figure 27.7 Formation of enzyme-substrate complex

An enzyme has a special site on its surface, called the active site, which binds the substrate molecule and converts it into the products.

Enzymes are highly specific, each enzyme acts on only one particular substrate molecule. This specificity is due to the active site of the enzyme, which has a unique shape that allows only a specific substrate to fit into it. The random movement of enzyme and substrate molecules, allows the substrate to enter the enzyme active site. As a result of this, a temporary enzyme–substrate complex is formed. After this, the products are released, and the enzyme remains unchanged and free to bind with another substrate molecule **(Figure 27.7)**.

This mechanism can be understood by using the lock and key model proposed by Emil Fischer in 1894. According to this model, the lock is the enzyme and the key is the substrate. Only the correctly shaped key (substrate) fits into the keyhole (active site) of the lock (enzyme).

27.3.1 Factors Affecting Enzyme Activity

The important factors that influence the activity of the enzyme reaction are temperature, pH and change in substrate and enzyme concentration. The enzyme action may also be affected in the presence of some other substances such as co-enzymes, activators and inhibitors.

Temperature and pH: The temperature and pH that give maximum enzyme activity are called optimum temperature and pH, respectively. If the temperature and pH are disturbed from the optimum values, it can deactivate the enzyme action. The enzymatic reactions in the human body and other organisms occur best at or around 37 °C and a pH range of 6.4-6.9.

Concentration of enzyme and substrate: The rate of an enzymatic reaction increases as the enzyme or substrate concentrations are increased. This is because with more substrate and enzyme molecules the available sites for binding to enzyme are also abundant. Therefore, the reaction rate increases due to the formation of more enzyme-substrate complex. However increasing the substrate concentration beyond a limit can slow down the reaction.

27.3.2 Role of Inhibitors in Enzyme-Catalyzed Reactions

A variety of small molecules or ions that cause enzymes to lose their catalytic activity are called inhibitors. Although, different inhibitors behave differently, but they all prevent the active site from binding with a substrate.

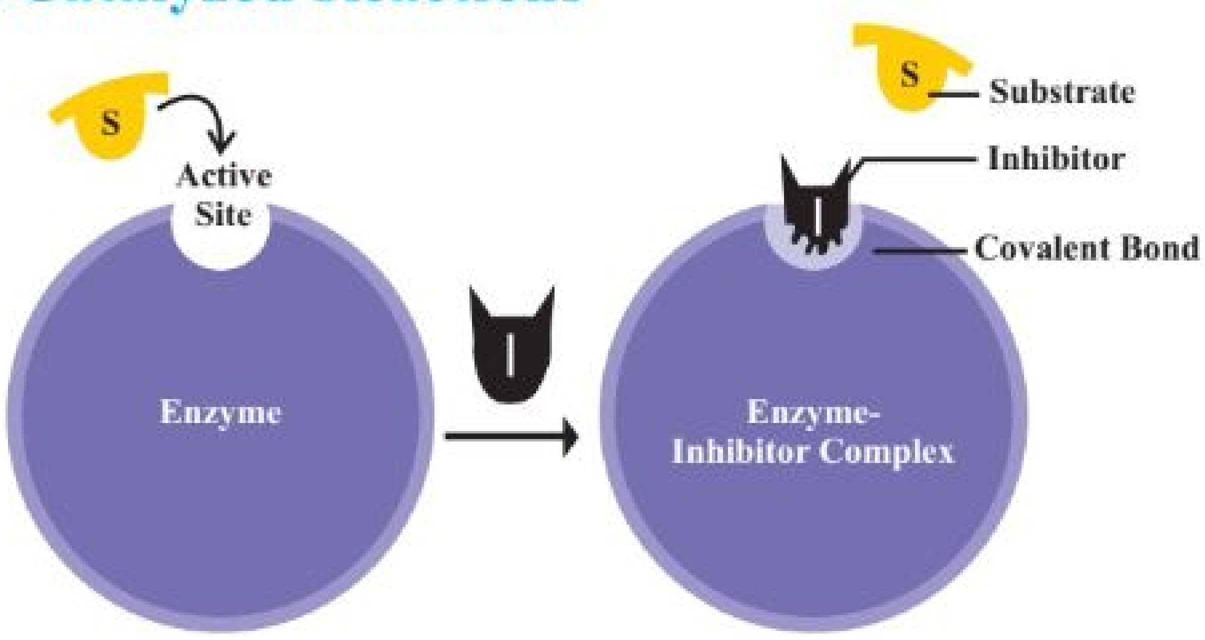


Figure 27.8 Action of reversible inhibitor

Reversible inhibitors are also termed as competitive inhibitors as they are the molecules having the same shape as that of the substrate. The substrate and the inhibitor compete for the active site of the enzyme. The more the inhibitor, the more deactivated is the enzyme for the original substrate. For example, the substrate butanedioate (succinate ion) is oxidized by the enzyme dehydrogenase succinate. The propandioate ion (malonate) can inhibit this enzyme due to its resemblance with the substrate butanedioate.

$$^{-}OOC - CH_2 - CH_2 - COO^{-} \qquad ^{-}OOC - CH_2 - COO^{-}$$

succinate ion   malonate ion

Non-competitive inhibitors (irreversible) are small ions or molecules that change the shape of the active site such that it is no longer available for the substrate. Thus, such inhibition is irreversible and it sometimes causes severe human health issues or even death. An enzyme to which an irreversible inhibitor, such as poisons, antibiotics, anti-metabolites and some drugs, is attached, loses enzymatic activity permanently **(Figure 27.9)**.

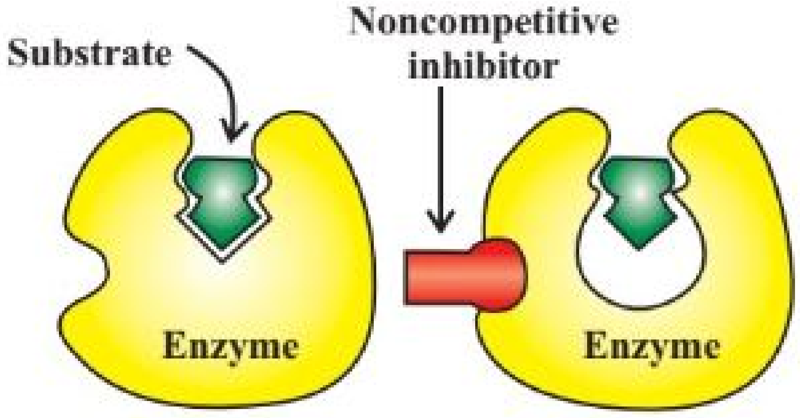


Figure 27.9 Action of non-competitive inhibitor

Penicilin is an irreversible inhibitor that blocks the enzyme trans-peptidase. This enzyme acts for the synthesis of the bacterial cell wall. Thus insulin kills bacteria by disrupting the cell wall enzyme.

Quick Check 27.3

a) How do enzymes differ from inorganic catalysts?
b) What is the effect of decreasing and increasing temperature affect an enzyme activity?
c) Differentiate between competitive and non-competitive inhibitors.
d) An enzyme is a protein. When the pH is changed, the function of the enzyme is disturbed. In terms of the protein structure, explain how and why it happens so?

The cobra venom has an enzyme PLA2, which can disrupt the cell wall of the red blood cell. This result in hemolysis, which causes swelling of the affected organ and ultimately death.

27.4 LIPIDS

Lipids are a class of organic compounds found in animals and plants that include fats and phospholipids (such as those in the cellular membrane), steroids, and terpenes (essential oils). Unlike, polysaccharides and proteins, lipids are not polymers, lacking repeating monomeric unit. They are hydrophobic but soluble in organic solvents. Lipids perform many different functions in living systems as fuel molecules, signal molecules, components of membranes, hormones and intracellular messengers. Lipids are broadly classified into simple lipids, complex lipids and derived lipids based on their chemical composition.

27.4.1 Simple Lipids

These are esters of fatty acids with different type of alcohols. Simple lipids are sub-classified based on the type of alcohols, such as fats, oils, and waxes.

Triglycerides

Animal fats and vegetable oils are esters formed from one glycerol molecule and three fatty acids, forming triglycerides as shown in **Figure 27.10**. The fatty acids may be similar or different. This structure makes them efficient energy storage molecules and also provides insulation, protection of organs, and a source of fat-soluble vitamins.

Saturated fatty acids make lipids that are solid at room temperature and are called fats.

Oil contain unsaturated fatty acids with one or more double bonds.

The hydrophobic nature of fatty acid chains makes fats insoluble in water but soluble in organic solvents. In the body, this property allows them to form insulating layers under the skin and cushioning around organs such as the kidneys, helping in temperature regulation and protection.

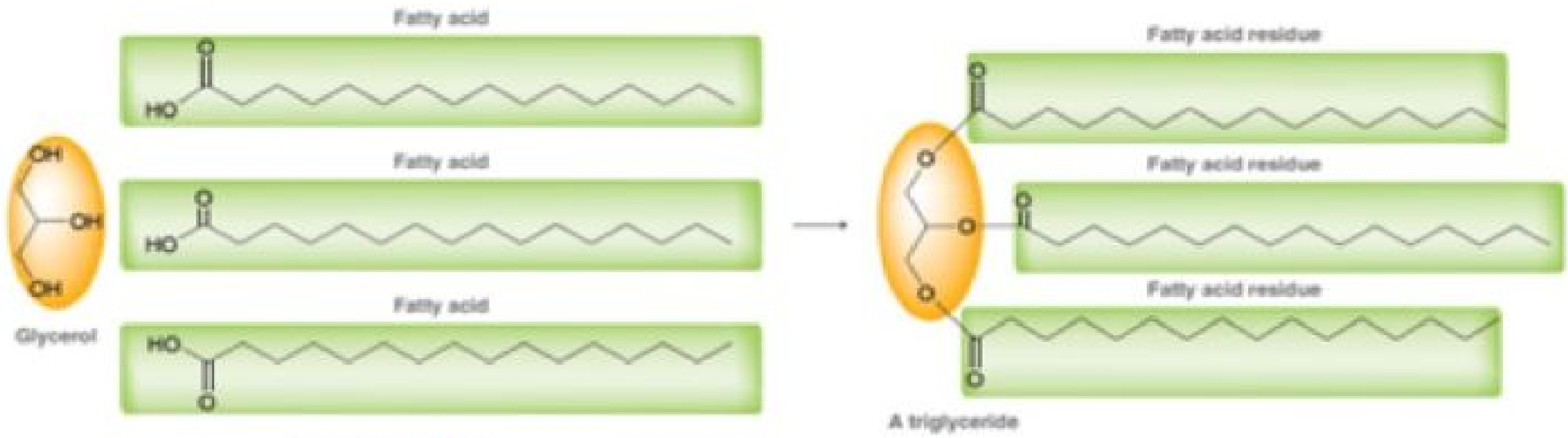


Figure 27.10 Glycerol and fatty acids combine to give triglycerides.

Waxes

Most waxes are made up of long fatty acid chains esterified to long-chain alcohols. Both chains are nonpolar and hydrophobic (water-repelling). Because of the hydrophobic nature of waxes, they serve as barrier by forming protective coatings, which prevents water from sticking on the surface. For example, those seen in nature include beeswax, the oil in a whale's head, the feathers of some aquatic birds and plant waxes. These are widely used in pharmaceutical, cosmetic and other industries in the manufacture of lotions, ointments and polishes, etc.

$$CH_3-(CH_2)_{34}-\overset{\overset{\displaystyle O}{\|}}{C}-O-(CH_2)_{35}-CH_3 \qquad \textbf{Beeswax}$$

27.4.2 Compound Lipids

These are esters of fatty acids with alcohols containing an additional group, such as phosphate, nitrogenous base, carbohydrate, protein etc. A phospholipid is similar to a fat molecule but has only two fatty acids attached to glycerol instead of three. The third hydroxyl group of glycerol is linked to a phosphate group, which makes the molecule polar. The hydrocarbon tails are hydrophobic, while the phosphate group and its attached components form a hydrophilic head that has an affinity for water **(Figure 27.11)**.

When phospholipids are added to water, they turn into a double-layered sheet called a "bilayer". The polar ends face outward and the non-polar ends clustered together in their own layer. It forms the structure of all cell membranes. Some liposomes are artificial phospholipids that are used for hydrophilic drug delivery.

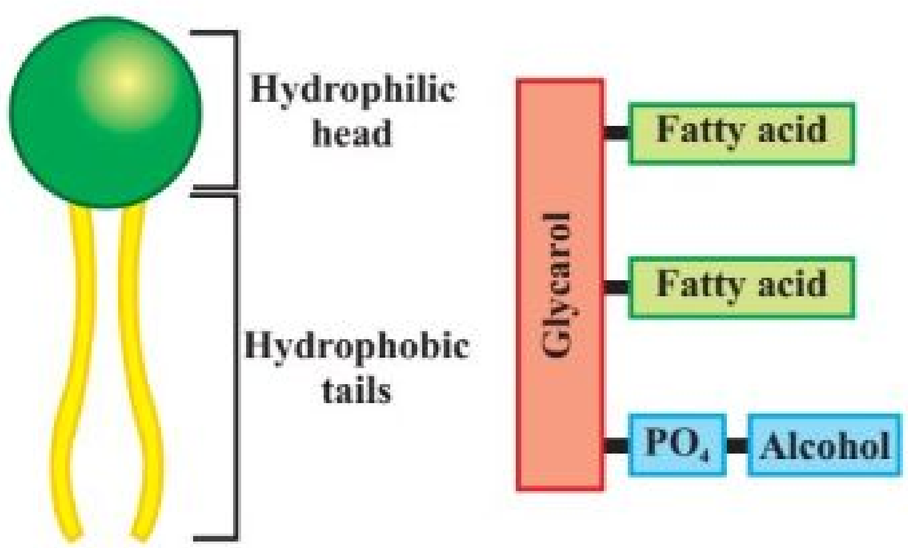


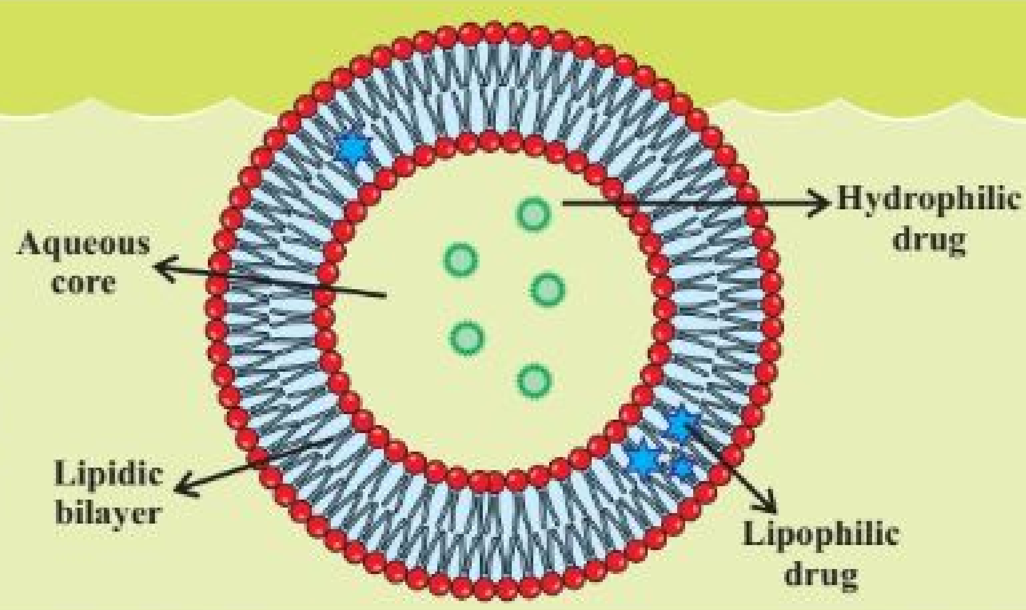
Figure 27.11 Phospholipids basic structure

Lipoproteins are complexes of lipids and proteins that transport hydrophobic lipids (like cholesterol and triglycerides) in the bloodstream.

Glycolipids are lipids with carbohydrate (sugar) groups attached, mostly found in nervous tissue.

Did You Know?

Liposomes are ideal for delivering hydrophilic (water-loving) cancer drugs beacuse their structure, a lipid bilayer surrounding a watery core, allows them to encapsulate water- soluble agents, shielding them from degradation and enabling cellular uptake. They improve solubility, provide targeted delivery to the tumor cells.



27.4.3 Derived or Associated Lipids

They are the hydrolytic products of simple and compound lipids, which have the same characteristics as of lipids, e.g. fatty acids, glycerol, steroids, lipid soluble vitamins, etc. They are not fats themselves, but come from fats. They perform important roles in the body including energy and hormone production, cell structure, nerve health, and vitamin function.

Steroids

Steroids are not formed from fatty acids but have some lipid like properties. They consist of three cyclohexane rings and one cyclopentane ring fused together called steroid nucleus **(Figure 27.12)**. The four rings in the steroid nucleus are named as A, B, C, and D. Many steroids also have the –OH functional group, which put them into the alcohol class (sterols). There are numerous steroids in the biological systems, including cholesterol, bile salts, vitamin D and steroid hormones.

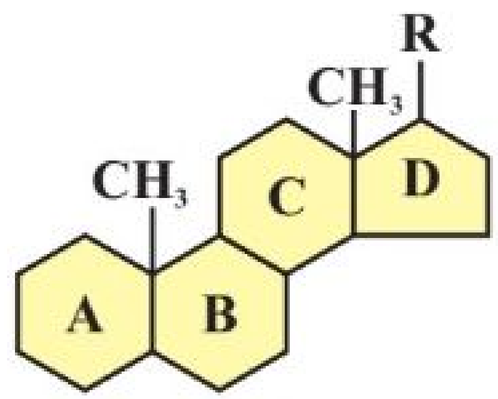


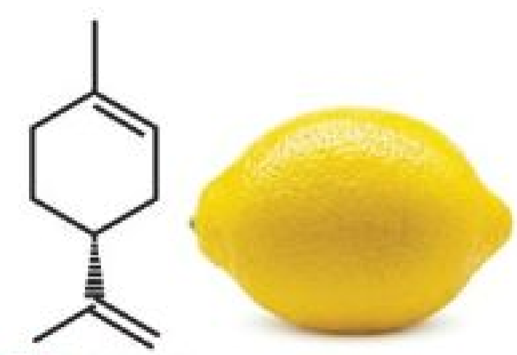
Figure27.12 Steroid ring structure

Terpenes

Lipids present in plants include a wide variety of hydrocarbons called terpenes, which are built from isoprene ($CH(CH)_3$=CH-CH_2CH_3) units. These hydrocarbons and their oxygenated derivatives have fewer than 40 carbon atoms. Terpenes that contain 40 carbon atoms are known as carotenoids.

27.4.4 Nutritional and Biological Importance of Lipids

A major function of lipids is to serve as a primary source of energy storage in living organisms. They provide more energy per gram than carbohydrates, because when oxidised to carbon dioxide and water, they have a higher caloric value.



Limonene (a terpene)

Limonene, a terpene in lemon

Lipids act as solvents for the transport of fat vitamins (A, D, E and K) and help in their absorption in the intestinal cells and later into the bloodstream. We can meet our vitamin requirements by consuming foods that contain these fat-soluble vitamins. These vitamins should be eaten with a bit of healthy fat. Fats provide insulation to the body from water, heat, and electricity due to their non-polar nature.

Did You Know?

Animals, such as polar bears, reptiles, and amphibians, store extra fat when hibernating. Hibernation is a condition when animals significantly slow down their metabolic rate, body temperature, heart rate and breathing to save energy for the periods when food is scarce. During this period, metabolic rates decrease extremely. Fat is a more concentrated source of energy compared to glycogen, allowing animals to utilize stored fat effectively while minimizing energy consumption.

Quick Check 27.3

a) Why lipids are not soluble in water?
b) What are three major functions of lipids in the human body?
c) What type/s of lipid do/does not contain fatty acids? Give examples.
d) Vegetable oil and vegetable ghee both are triglycerides. What is the major structural difference between the two?

27.5 NUCLEIC ACIDS

Nucleic acids are large biomolecules that store and transmit genetic information. They are polymers made up of smaller units called nucleotides. Nucleic acids are formed from the nucleotide chains containing alternating sugar and phosphate groups with organic bases attached to the sugar molecules. The sugars are ribose in RNA and deoxyribose in DNA; these are five-membered sugar molecules. Nucleotides joined together by a phosphodiester linkage with the '5' and '3' carbon atoms of the sugar to form nucleic acids **(Figure 27.13).** The process is repeated up to several million times to make a polynucleotide. Phosphodiester linkages are strong covalent bonds, which gives strength and stability to the polynucleotide chain.

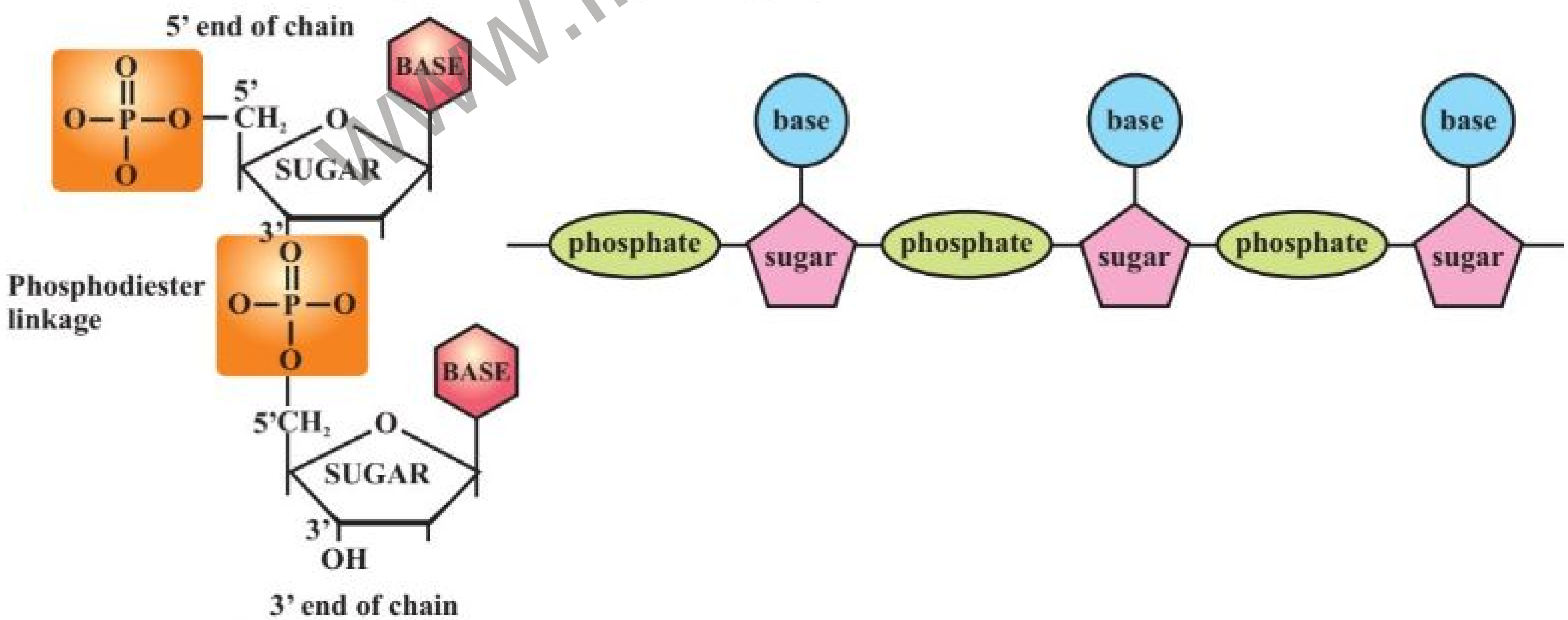


Figure 27.13 The general structure of nucleotide chains in nucleic acids (DNA and RNA)

27.5.1 Deoxyribonucleic Acid (DNA)

DNA is present in the nucleus of every living cell. It is a coded plan (or 'blueprint') for making proteins, which are, in turn, vital for life. Each specific protein is made by a specific gene; a section of DNA **(Figure 27.14)**. The genetic information of an organism is stored in DNA molecules that carries the genetic instructions for the development, functioning, growth, and reproduction of all living organisms. The double helix structure of DNA allows for the storage of information through the sequence of its four different nitrogenous bases and transmit genetic information efficiently and accurately for the synthesis of proteins.

These genes are organised into larger units called **chromosomes**; in humans, we receive 23 pairs of these from our parents. While nearly every cell in the body carries the full set of 23 pairs, each cell is a different specific pectine. For instance, a red blood cell activates the gene for haemoglobin while keeping the gene for keratin switched off.

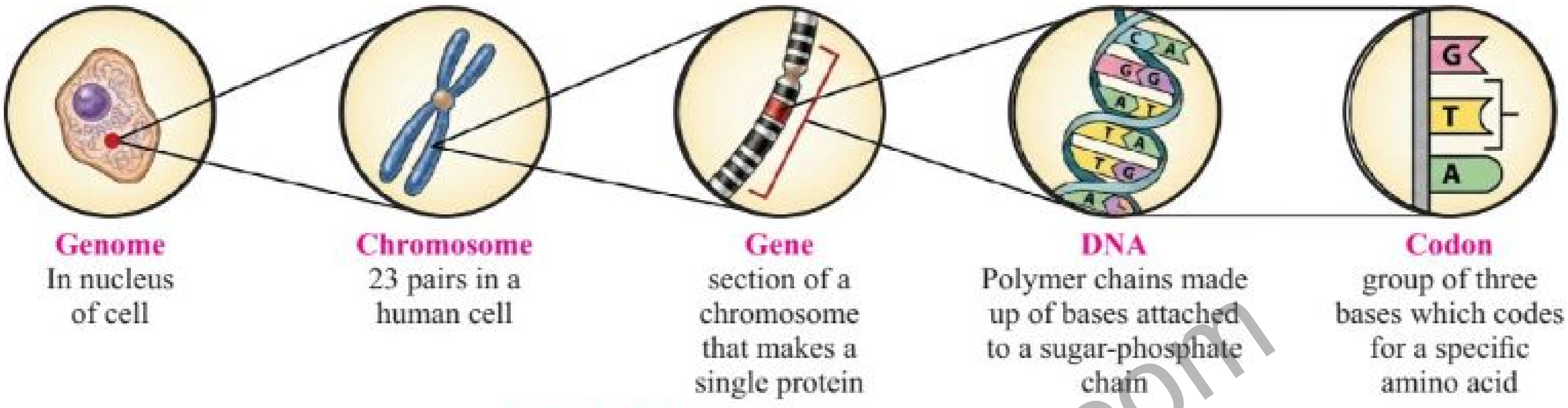


Figure 27.14 DNA; from genome to codon

The structure and function of DNA

In 1953, James Watson and Francis Crick showed that DNA consists of two polynucleotide chains. Each chain forms a right-handed helical spiral and the two chains coil around each other to form a double helix. The two polynucleotide chains are not identical but opposite to each other due to base pairing i.e. '3' end of one faces the '5' end of the other. Each chain has a sugar-phosphate backbone with bases which project at right-angles and held by weak hydrogen bonds with bases of the opposite chain across the double helix. Adenine (A) is always opposite to thymine (T), and guanine (G) and cytosine (C) are opposite to each other. There are two hydrogen bonds between A and T pair, and three hydrogen bonds between G and C pair **(Figure 27.15)**.

Figure 27.15 Structure of DNA

Genes are the specific regions of DNA that carry genetic information. They provide instructions for the cell to make a particular protein. One important process of DNA is its self-replication. Replication is the process during the cell cycle in which DNA is copied, so that when the cell division occurs, each new cell receives a complete set of genetic material. In this way, the genetic information is transmitted from one cell to the daughter cells and to the next generation.

27.5.2 Structure of RNA

Figure 27.16 Structure of RNA

RNA is usually single stranded unlike DNA, but the chain can fold back to itself to form a helical loop. A ribonucleotide chain in the RNA contains ribose, four nitrogenous bases (A, U, G, and C), and the phosphate group as given in **Figure 27.16.** There are three major types of RNA in the cells.

Messenger RNA (mRNA): it carries the genetic blueprint copied from the DNA in the nucleus.

Ribosomal RNA (rRNA): it helps to make up the ribosome.

Transfer RNA (tRNA): it translates the nucleotide sequence in mRNA into the corresponding sequence of amino acids in a protein.

27.5.3 The Genetic Code and Protein Synthesis

Protein synthesis is a complex process involved in transferring genetic information encoded in the DNA. Two processes, transcription and translation are required for transmitting genetic information for the synthesis of numerous proteins in living organisms. The process starts with replication, i.e. making copies of DNA in the nucleus, the genetic instructions for making a protein are copied from a DNA gene into mRNA; this process is called *transcription.* When the mRNA strand is complete, it detaches from DNA and enters the cytoplasm, where it attaches to ribosomes. At the ribosomes, the code carried by mRNA is read and converted into a specific sequence of amino acids, forming a protein through the process called *translation*. Amino acids are arranged according to the sequence of bases in the RNA. The tRNA molecules release their amino acids, which join together in a chain, forming a polypeptide chain. The polypeptide chain grows as bonds form between the amino acids, and finally the complete protein molecule is formed.

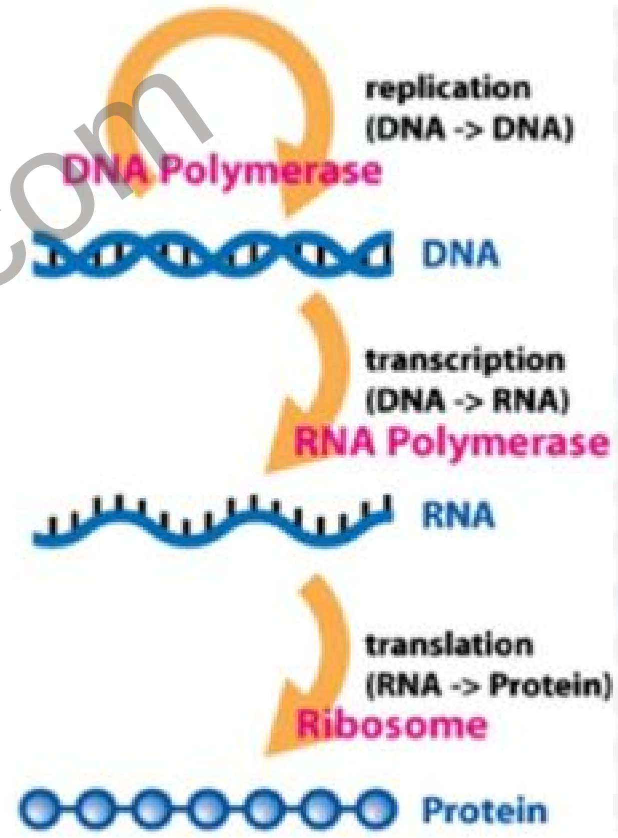


Figure27.17 Protein synthesis

Quick Check 27.4

a) Compare the stability provided by the **sugar-phosphate backbone** versus the **inter-chain base pairing**. In your answer, refer to the specific types of bonds and the number of bonds formed between:
- Adenine (A) and Thymine (T)
- Guanine (G) and Cytosine (C)

b) How the DNA and RNA are chemically different? What are the similarities between these two?

c) Nearly every cell in the human body contains the exact same 23 pairs of chromosomes, yet a red blood cell produces haemoglobin while a skin cell produces keratin. Explain why.

27.5 MINERALS

Minerals are inorganic substances, necessary for the maintenance of certain physiochemical life processes vital for living organism. Although, they produce no energy, they have important functions to perform in various activities.

Minerals may be broadly classified as macro (major) or micro (trace) elements. The macro-minerals include calcium, phosphorus, sodium and chloride, while the micro-elements include iron, copper, cobalt, potassium, magnesium, iodine, zinc, manganese, molybdenum, fluoride, chromium, selenium and sulfur. The macro-minerals are required in amounts greater than 100 mg/dL and the micro-minerals are required in amounts less than 100 mg/dL.

Table 27.1 Sources and role of iron, calcium, phosphorus and zinc in nutrition

Mineral	Sources	Role in Nutrition
Iron	Liver, meat, egg yolks, nuts, enriched or whole grains, beans, peas and lentils.	Hemoglobin synthesis found in red blood and myoglobin in muscle cells. Needed to carry oxygen.
Calcium	Milk and other dairy products, greens, broccoli, and salmon, sardines, beans,peas and lentils.	Helps in the formation of bones and teeth, normal blood clotting, muscle contraction and relaxation, heart function and nerve function.
Phosphorus	Meat, fish, poultry, eggs, milk, cereal products.	Aids in the formation of bones and teeth. Regulates the release and use of body energy (ATP). It helps to carry fat in the body as a part of phospholipids. Maintains normal acid/base balance in the body.
Zinc	Meat, seafood, whole grains.	Component of many enzyme systems e.g. involved in growth, immune function, etc. Found in the hormone insulin.
Sodium, potassium, and chloride	Salt, meat, sea food, fruit juices, vegetables, lentil	Maintaining fluid balance, nerve transmission, and muscle function

Exercise

Q1. Multiple Choice Questions:

I. Glucose is a building block for all, except:

a) cellulose b) glycogen
c) inulin d) starch

II. Which one of the following is not an aldose?

a) glucose b) galactose
c) mannose d) fructose

III. Which one of the following element is not present in all proteins?

a) carbon b) hydrogen
c) nitrogen d) sulphur

IV. In DNA, the linkages between different nitrogenous bases are:

a) phosphate linkage b) hydrogen bonding
c) glycosidic linkage d) peptide linkage

V. Which one of the following nitrogenous bases is not common to RNA and DNA?

a) cytosine b) adenine
c) thiamine d) uracil

VI. Waxes are the esters of:

a) glycerols b) sterols
c) ethanol d) long-chain fatty acids and alcohols.

VII. A cell membrane is made up of:

a) phospholipid bilayer b) lipid
c) phospholipid d) only protein

VIII. The bonds in protein structure that are not broken on denaturation.

a) hydrogen bonds b) peptide bonds
c) ionic bond d) disulfide bonds

IX. The backbone of nucleic acid structure is constructed by:

a) peptide bonds b) glycosidic bonds
c) phosphodiester bridges d) all of them

X. Which element prevents the development of tooth decay:

a) fluorine b) calcium
c) phosphorus d) sodium

Q2. SHORT ANSWER QUESTIONS:

a) What role does glycogen play in the human body?

b) Point out the main structural difference between the compounds in each of the following pairs.

i) Glucose and fructose ii) Cellulose and starch
iii) Competetive and non-competitive inhibition iv) Glycolipids and lipoprotein

c) Which class of biomolecule contains each of the following linkages? Describe the function of each linkage.

i) Glycosidic ii) Peptide
iii) Ester iv) Phosphodiester

d) How the tertiary structure of proteins is formed?

e) In what way fats and oils are different?

f) Describe the structure of steroids. Write a note on the functions of cholesterol.

g) Describe the mechanism of enzyme action.

h) Why does an enzyme catalyze a reaction of only a specific substrate?

i) Name different RNAs and discuss their function.

j) What are some sources of potassium, iron, calcium, magnesium and zinc in our diet?

k) What is the role of iron in the body?

l) How enzyme inhibitors are important in our body and medicine?

Q3. Construction Response Questions

a. Why does the digestive enzyme pepsin have an optimum pH of 2?

b. How condensation of sugars and condensation of amino acid are same?

c. Why is cholesterol included in the lipid family?

d. Why fats and oils are also called triacylglycerols?

e. How hydrogen bonding is important in the double helix of DNA?

f. If the sequence T-A-C-C-G-A located on one strand of DNA, what sequence would be seen opposite to it on the other strand?

DESCRIPTIVE QUESTIONS

Q4. Classify and describe the structure of polysaccharides.

Q5. How the structure of proteins support its function. Describe at each structure level.

Q6. Write an account of classification of lipids with suitable examples.

Q7. What are nucleic acids? Describe the roll of DNA and RNA in the protein synthesis.