other to form a comparatively larger and complex molecule, i.e., quaternary structure. Quaternary structure is the spatial arrangement of the protein subunits. These subunits are stabilised by hydrogen bonds, electrostatic intercations, ionic bonds and disulfide bridges. Depending upon subunit numbers, the quarternary structures may be dimer, trimer, etc. Identical protein subunits form homodimer, homotrimer, etc. whereas non-identical subunits form heterodimers, heterotrimer, etc. The quaternary structure of haemoglobin is given in Fig. 3.28.

3.5 NUCLEIC ACIDS

The cell organelles, namely nucleus, mitochondria and chloroplast contain nucleic acid within them. Within nucleus, nucleic acids are associated with histone proteins to form chromatin. Nucleic acids are polymers of nucleotides linked through phosphodiester linkages. Two types of nucleic acids are present in cells, namely deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). DNA acts as a genetic material and inherits the information from one generation to next. However, RNA serves as genetic material in some viruses.

Nucleotides of DNA and RNA are made up of nitrogenous base, sugar and phosphate. The sugar that is present in nucleic acids is pentose sugar which is of two types; the one present in DNA is 2′**-deoxy-D-ribose,** and the other present in RNA is **D-ribose**. Both the pentoses are present as closed five membered rings (Fig. 3.29). For numbering pentoses of nucleotides the carbon numbers are given a prime (′) designation to differentiate them from the numbered atoms of the nitrogenous bases.

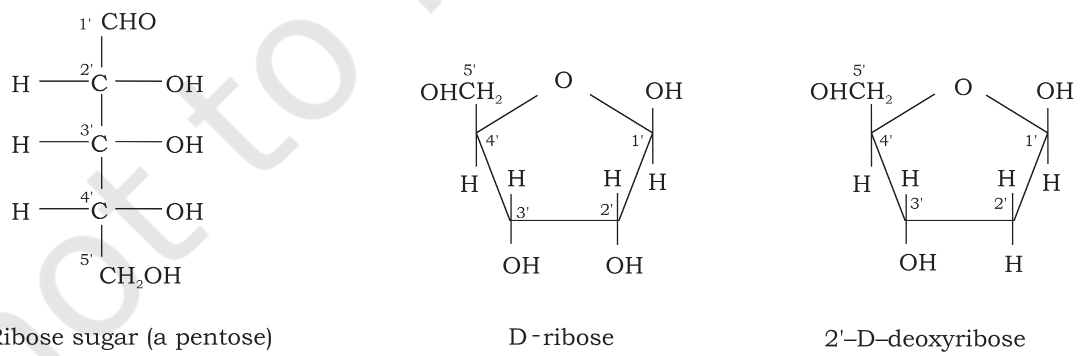

Fig. 3.29: Structure of pentose sugars present in nucleic acids

Nitrogenous bases are of two types; **purines** and **pyrimidines**. The two purine bases of DNA and RNA are **adenine (A)** and **guanine (G)**. Among pyrimidines, **cytosine (C)** is present in both DNA and RNA, **thymine (T)** is present in DNA only and **uracil (U)** is present in RNA only. The structure of five major bases is shown in (Fig. 3.30). The purine and pyrimidine bases contain aromatic ring structures which absorb light at a wavelength near 260 nm.

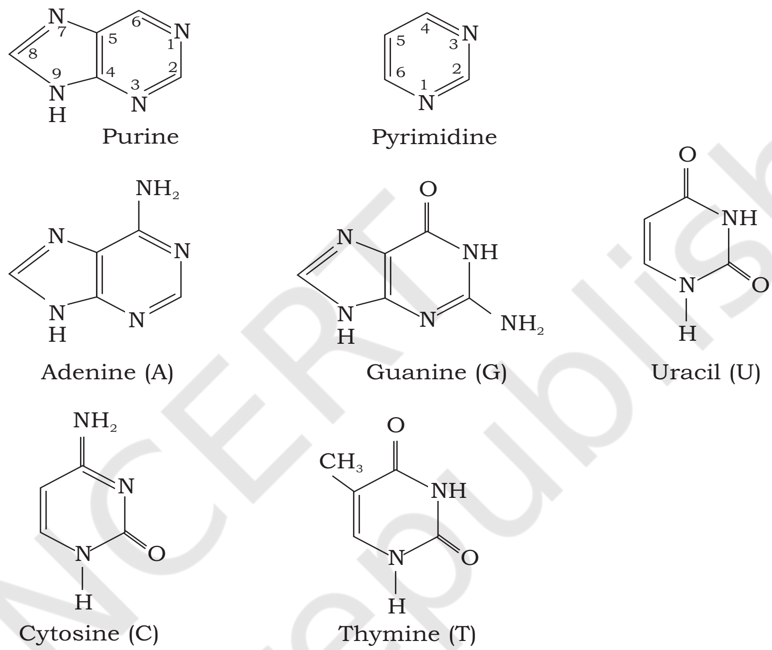

Fig. 3.30: Structure of nitrogenous bases present in nucleic acids

A base (either purine or pyrimidine), a pentose sugar unit and a phosphate group are linked together to form a **nucleotide**. On the other hand, a base linked only to a pentose sugar unit without a phosphate group is called a **nucleoside**. The four nucleosides of DNA are named as deoxyadenosine, deoxyguanosine, deoxycytidine, and deoxythymidine. The nucleotides in DNA are called deoxyribonucleotides or deoxyribonucleoside-5'-monophosphates, which form the structural unit of DNA. They are of four types namely; deoxyadenylate (deoxyadenosine-5'-monophosphate; dAMP), deoxyguanylate (deoxyguanosine-5'-monophosphate; dGMP), deoxycytidylate (deoxycytidine-5'-monophosphate; dCMP) and deoxythymidylate (deoxythymidine-5'-monophosphate; dTMP) (Fig. 3.31). Nucleotides in DNA are indicated by prefix 'd' as they contain deoxyribose rather than ribose sugar.

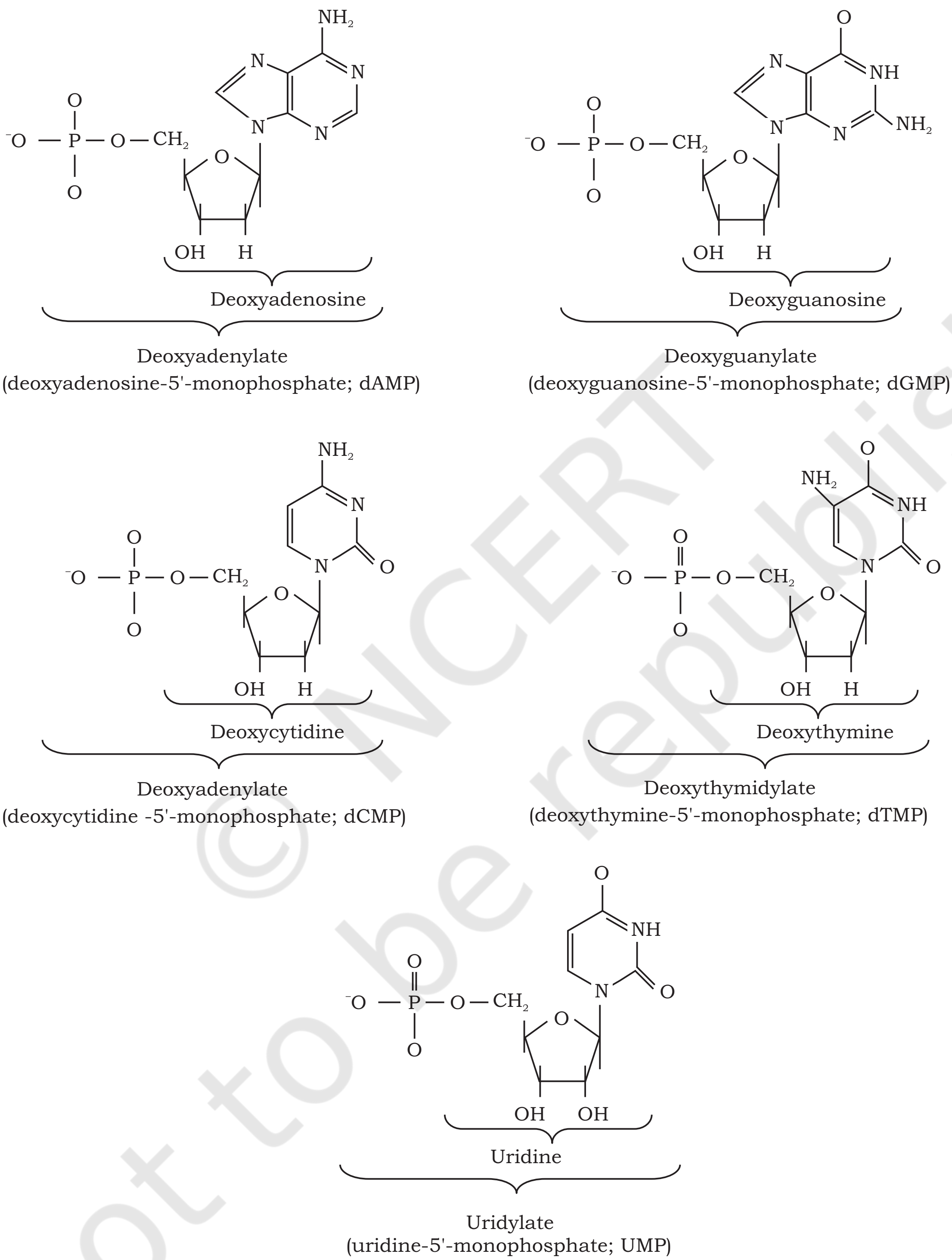

Fig. 3.31: The nucleosides and nucleotides present in DNA and RNA

The four nucleosides of RNA are called adenosine, guanosine, cytidine, and uridine, which, when bound to a phosphate group, make ribonucleotides or ribonucleoside-5'-monophosphate. There are four types of ribonucleotides namely; adenylate (adenosine-5'-monophosphate; AMP), guanylate (guanosine-5'-monophosphate; GMP), cytidylate (cytidine-5'-monophosphate; CMP) and uridylate (uridine-5'-monophosphate; UMP).

3.5.1 Polynucleotide chain

Nucleotides of both DNA and RNA are covalently linked, in which the 3' hydroxyl (-OH) group of the sugar of one nucleotide unit is esterified to -OH group of phosphate attached to 5' carbon atom of the sugar of the next

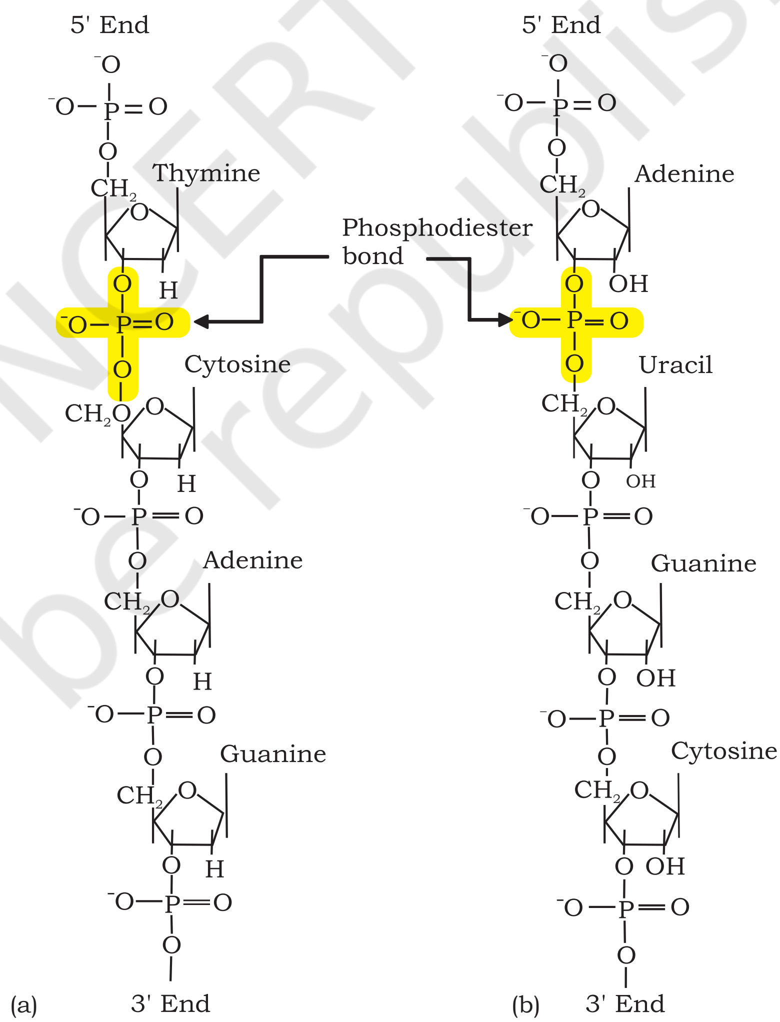

Fig. 3.32: Primary structure of (a) DNA and (b) RNA

nucleotide, forming a phosphodiester linkage (Fig. 3.32). Like a polypeptide chain, a polynucleotide chain has a specific polarity, i.e., distinct 5' and 3' ends. The 5' end has phosphate group at C-5' of sugar while 3' end has free -OH group at C-3' of ribose. The base sequence in a polynucleotide chain is written in the 5'→3' direction.

James Watson and Francis Crick in 1953 proposed the double helical (three dimensional) structure of DNA (Fig. 3.33 (b)). It consists of two polynucleotide chains of DNA wound around the same axis to form right handed double helix. The two strands are oriented antiparallel, i.e., their 3' and 5' phosphodiester bonds run in opposite directions. The sugar and phosphate form the backbones of the double helix and exposed to the polar environment. The bases of both the strands are stacked inside the core of the double helix and make it hydrophobic. Within the helix each nucleotide base of one strand makes hydrogen bonds in the same plane with the base of the other strand. A of one strand forms two hydrogen bonds with T of the other strand (A=T) and *vice versa* and G on one strand forms three hydrogen bonds with C on the other strand (G≡C) and *vice versa* (Fig. 3.33 (a)).

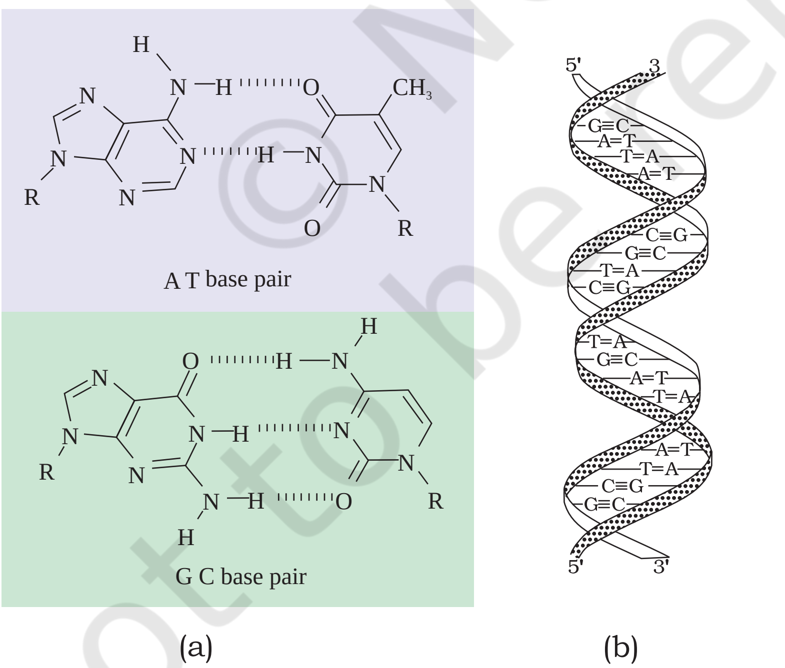

Fig 3.33: (a) Base pairing in DNA and (b) Watson-Crick double helical model of DNA

The Watson-Crick structure of DNA is also known as B-DNA. B-DNA is the most stable form of DNA. The other two structural variants are A-DNA and Z-DNA. A-DNA is right handed double helix. It is wider and contains 11 base pairs per helix. Z-DNA is left handed double helix with 12 base pairs per helix.

The bases of two strands of DNA double helix are joined by hydrogen bonds [Fig. 3.33 (a)]. Heating disrupts hydrogen bonds between the base pairs, and thereby separation of the two strands of DNA takes place called **denaturation** or **melting**. The temperature at which half of the DNA is denatured is called **melting temperature (T_m).** Apart from heating, melting is also caused by acid or alkali. The two strands of nucleic acids that are separated by melting, can spontaneously reassociate to form a double helix if temperature is decreased below T_m. This process of reassociation or renaturation is called **annealing**.

Fig 3.34: Schematic representation of a typical prokaryotic mRNA

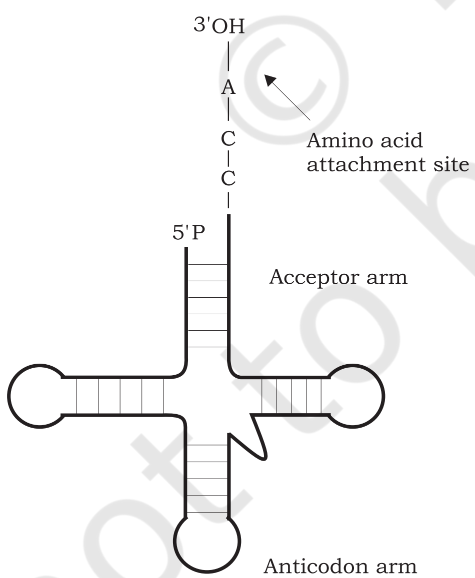

Fig. 3.35: Structure of a tRNA molecule

3.5.2 Types of RNA

Messenger RNA (mRNA)

It is a single strand linear polyribonucleotide chain that carries genetic information from DNA to ribosome. At the 5' end is UTR (untranslated region) containing no genetic information for polypeptide synthesis. It is followed by initiation codon, coding region and stop codon. At the 3' end is present another UTR (Fig. 3.34). In eukaryotic mRNA, 5' end contains guanylate which is methylated at its N-7. This process is called capping. 3' end of mRNA also undergoes polyadenylation (addition of several adenylate residues).

Ribosomal RNA (rRNA)

It forms the structural components of ribosomes. 70S prokaryotic ribosomes have 16S rRNA in smaller subunit (30S), 23S and 5S rRNAs in larger subunit (50S). The eukaryotic ribosome (80S) has 18S rRNA in smaller subunit (40S) and 28S, 5.8S and 5S rRNAs in larger subunit (60S).

Transfer RNA (tRNA)

These are small RNA molecules that transfer amino acids to ribosome during protein synthesis. It is a single ribopolynucleotide chain folded to form four arms. The acceptor arm has a CCA sequence at 3'OH end which is amino acid binding site (Fig. 3.35). The anticodon arm has anticodon, a set of three bases which recognises a specific codon of mRNA during translation.

SUMMARY

- Carbohydrates are made up of carbon, hydrogen and oxygen atoms, and are widely distributed in animal and plant tissues.
- Carbohydrates are categorised into 4 major classes, namely monosaccharides (e.g., glucose, ribose), disaccharides (e.g., sucrose, lactose), oligosaccharides (e.g., raffinose) and polysaccharides (e.g., starch, glycogen).
- Monosaccharides can be classified as trioses, tetroses, pentoses, hexoses, etc., depending on the number of carbon atoms in the molecule.
- Pentose sugar such as ribose is an important component of nucleic acids, coenzymes.
- Two monosaccharides linked by glycosidic bond make a disaccharide (e.g., sucrose).
- Polysaccharides perform various roles as the storage form of energy and also as structural component.
- Lipids are organic compounds found in living organisms. These are made up of hydrophobic fatty acid chains linked to glycerol via ester bond.
- Fatty acids are long chain hydrocarbon containing carboxylic acid group. Fatty acids may be saturated (having no double bonds) or unsaturated (having one or more double bonds). Nomenclature of fatty acids is based

on total number of carbons, total number of double bonds and position of double bonds.

- Lipids are broadly classified into two classes–simple and compound lipids.
- Simple lipids include triacylglycerol and waxes, which are esters of glycerol with fatty acids and esters of high molecular weight alcohol with fatty acids, respectively.
- Compound lipids include membrane lipids which are of two types, glycerophospholipids and sphingolipids. Compound lipids are amphipathic molecules made up of hydrophilic phosphate tails.
- Glycerophospholipid contains glycerol backbone and sphingolipids contain sphingoid base backbone.
- Steroids are another class of compound lipids made up of four-fused ring structure. Cholesterol is the most common steroid found in animals. It is the precursor of all steroid hormones and vitamin D.
- The amino acids are organic compounds containing amine ($-NH_2$) and carboxyl (-COOH) functional groups, along with a side chain (R group) specific to each amino acid.
- There are 20 standard amino acids and some non-standard amino acids (e.g. 4-hydroxy proline, 5-hydroxy lysine, etc.) and some non-protein amino acids (e.g., L-ornithine, L-citrulline, etc.)
- In a polypeptide chain, the amino acids are linked covalently via peptide bond in a linear fashion to make a protein.
- There are four levels of protein structures, namely primary, secondary, tertiary and quaternary.
- Primary structure of proteins is the linear chain of amino acid sequences linked through peptide bonds.
- Secondary structure of protein is the three dimensional form of polypeptide.
- The two major types of secondary structures are α-helix and β-sheets.
- Tertiary structure is the three dimensional arrangement of protein.
- Quaternary structure is the complex arrangement of folded protein subunits, stabilised through hydrogen bonds, electrostatic interactions, etc.
- Nucleic acids are the polymer of nucleotide which contain nitrogenous bases (adenine, guanine, cytosine, thymine and uracil), sugar and phosphate.

- Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA) are the two types of nucleic acids.
- DNA is genetic material of almost all the organisms except some viruses where RNA is the genetic material.
- DNA contains deoxyribose sugar and thymine while RNA contains ribose sugar and uracil in place of thymine.
- In DNA, adenine forms 2 hydrogen bonds with thymine (A=T) and cytosine forms 3 hydrogen bonds with guanine (C≡G).
- J.Watson and F.Crick (1953) described the three dimensional double helical structure of DNA.
- The mRNA, tRNA, rRNA are the major types of RNA.

EXERCISES

1. Describe the classification of carbohydrates.
2. Differentiate between D- and L-forms of glucose.
3. Draw the structure of a disaccharide made up of two monosaccharides glucose and fructose.
4. Draw the partial structure of starch and glycogen.
5. Write the major functions of carbohydrates.
6. Describe isomerisation in monosaccharides.
7. Differentiate between sphingolipids and glycerolipids.
8. Why are membrane lipids called amphipathic?
9. Differentiate between saturated and unsaturated fatty acids.
10. Describe the various categories of amino acids.
11. What is zwitterion and how is it developed?
12. What are non-standard and non-protein amino acids?
13. How the peptide bonds are formed?
14. Draw the structure of Lys-Glu-Lys.
15. Describe the various secondary structures of protein.
16. Differentiate between tertiary and quaternary structure of proteins.
17. Differentiate between nucleosides and nucleotides.
18. Explain the primary structure of DNA.

19. Draw the structure of A-T-C-G polynucleotide.
20. Explain Watson and Crick model of DNA.
21. Describe the various forms of DNA.
22. Describe the clover leaf model of tRNA.
23. In carbohydrates which of these functional groups are present
    (a) Alcohol and carboxyl groups
    (b) Aldehyde and ketone groups
    (c) Hydroxyl and hydrogen groups
    (d) Ether and ester groups
24. Which of the following is a non-reducing disaccharide?
    (a) Maltose
    (b) Lactose
    (c) Sucrose
    (d) Cellobiose
25. The repeating units of proteins are
    (a) Glucose units
    (b) Amino acids
    (c) Fatty acids
    (d) Nucleotides
26. Which of the following is the most common secondary structure of proteins
    (a) α-helix
    (b) β-pleated sheet
    (c) Both (a) and (b)
    (d) None of the above
27. A nucleotide contains
    (a) Nitrogenous base, sugar and phosphate
    (b) Sugar and phosphate
    (c) Nitrogenous base and sugar
    (d) None of the above
28. The two strands in DNA double helix are joined by
    (a) Covalent bond
    (b) Hydrogen bond
    (c) Glycosidic bond
    (d) Phosphodiester bond
29. Which is an example of storage lipid?
    (a) Fatty acids
    (b) Triacylglycerol
    (c) Sphingolipids
    (d) Eicosanoids
30. In glycerolipids fatty acids are joined to glycerol through which bond?
    (a) Phosphodiester bond
    (b) Glycosidic bond
    (c) Peptide bond
    (d) Ester bond