

NUCLEIC ACID

34.1 INTRODUCTION

Nucleic acid is the key molecule which supports life. Each life form or organism (bacteria, even viruses) contain nucleic acid without which they cannot reproduce or multiply. In this lesson you will learn the chemical nature of nucleic acids, different constituents and types of it, physical or three dimensional structure of nucleic acid molecule and their important biological functions. During study you may come across some technical term or unfamiliar chemical name. You should then turn to the terms you should know at the end of the .

34.2 OBJECTIVES

After reading this lesson, you will able to

- state chemical nature of nucleic acid
- state chemical components of nucleic acid
- explain the structure of DNA and RNA
- list the functions of DNA
- list the biological functions of RNA.

34.3 NATURE OF NUCLEIC ACID

Nucleic acid was first isolated by Frederick Miescher in 1869 as a phosphorous containing acidic substance from nuclei of pus cells, and hence the name "nucleic acid" was given. Decades later chemical nature of this nucleic acid was established. It was shown to be a long thread like molecule containing three distinct chemical constituents, i) phosphate group (ii) pentose sugar and iii) heterocyclic base.

34.4 CHEMICAL COMPONENTS OF NUCLEIC ACID

Two types of Pentose sugar are found in nucleic acids, deoxy-ribose and ribose. One kind of nucleic acid contains only deoxyribose and is called Deoxyribonucleic acid or DNA, the other kind contains only ribose and named as Ribonucleic acid or RNA. A cell contains both types. DNA mostly occur within nucleus; RNA occurs in nucleus as well as in cytoplasm. DNA and RNA also differ in their contents of heterocyclic bases. DNA contains two purines, adenine (A) and Guanine (G), and two pyrimidines, cytosine (C) and Thymine (T). RNA contains A, G and C, but instead of Thymine has uracil, a pyrimidine slightly different from thymine.

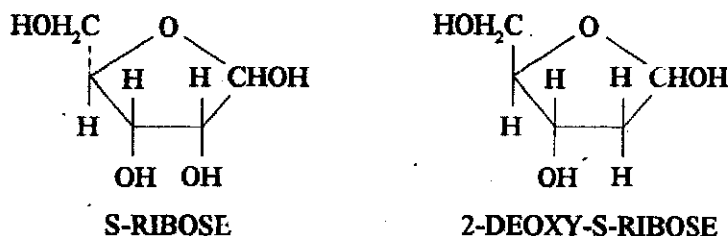


Fig. 34.1: Pentose Sugar .

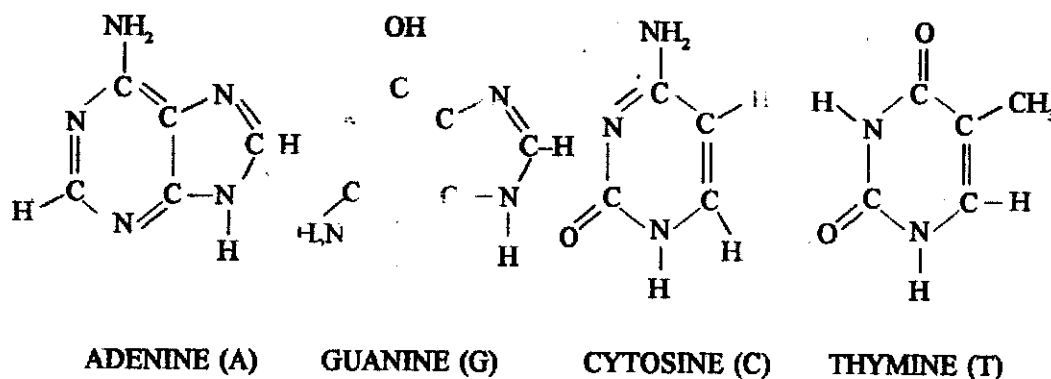


Fig. 34.2. Hetero cyclic bases in nucleic acids.

Nucleoside and Nucleotides

A purine or pyrimidine base when chemically joined to a sugar molecule the compound is called Nucleoside. Specific name of the nucleoside reflect the name of the sugar and the base both. For example, Purines are named as Adenosine (Adenine+ribose) Guanosine (Guanine+ribose), but pyrimidines are called Cytidine (Cytosine+ribose), Thymidine (Thymine+ribose). If the sugar is deoxyribose, the word "deoxy" is prefixed to the name e.g. deoxyadenosine and so on.

these, the bases are always covalently linked by glycosidic bond (see carbohydrate) to the first carbon atom (designated C_{1'}) of the ribose or monosachharide.

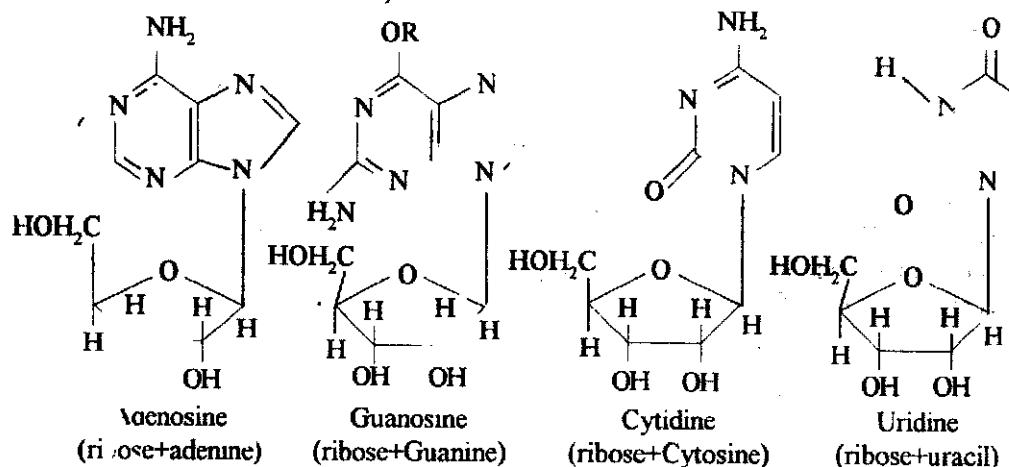
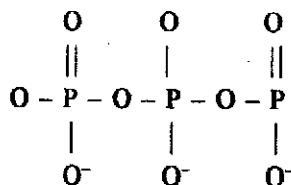


Fig 34.3: Nucleosides

When a phosphate group is attached to a nucleoside, the compound is called Nucleotide. Phosphoric acid can form ester bond with the free hydroxyl group of either third (C_3') or fifth carbon (C_5') atom of the Ribose. Thus chemically Nucleotides are 3' - or 5'-phosphate esters of nucleosides. More than one phosphate group can attach forming di- or triphosphates, which are also found in a cell. These molecules act as supplier of energy to carry out various chemical reactions in the body. The



bonds in triphosphates are called high energy bonds because on hydrolysis these bonds yield considerable amount of energy.

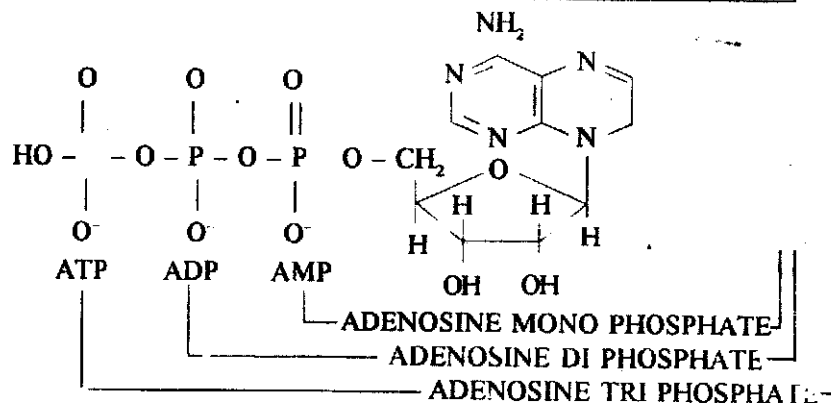
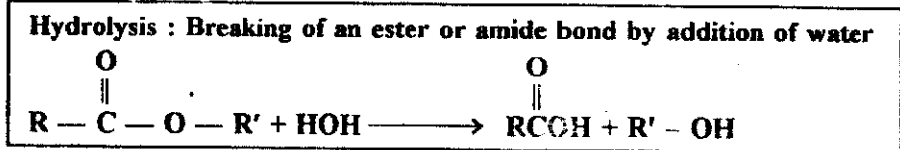


Fig. 34.4 Nucleotide

INTEXT QUESTIONS 34.1

1. Write chemical structures of Guanine and Thymine
.....
2. What is a nucleoside? Write chemical structures of Adenosine and cytidine.
.....
3. What is a nucleotide?
.....

34.5 CHEMICAL STRUCTURE OF DNA AND RNA

The monophosphates or Nucleotides can join with each other by 3'-5' phosphodiester bonds forming a long chain molecule in which the nucleotide is called the monomer joining to form a polymer molecule. As we have seen in previous sections, monosaccharides join to form polysaccharides (polymer) and monomeric unit of amino acids join to form polypeptides (proteins), nucleic acid similarly is polynucleotides. All these polymers i.e. proteins, nucleic acids and polysaccharides are found in biological systems and they are called biopolymers. In natural DNA or RNA, the polynucleotide chain is formed by 3'-5' phosphodiester bonds but since ribose has a 2'-hydroxyl group also, 2'-5' linked RNA chain is also possible.

SUGAR PHOSPHATE BACKBONE OF DNA

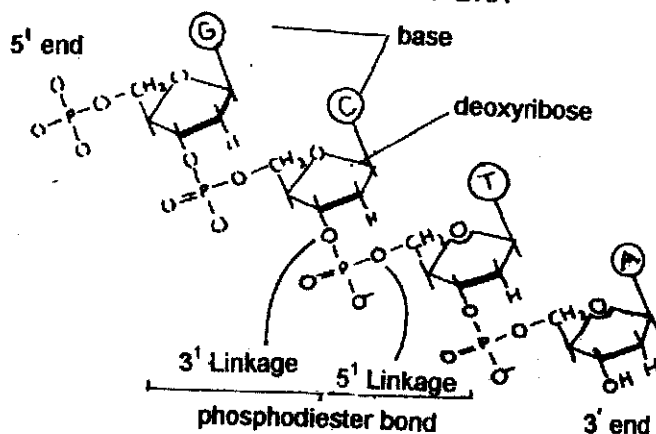


Fig. 34.5. Polynucleotide chain.

34.5.1 STRUCTURE OF DNA

The physical structure of DNA molecule was first proposed by Francis Crick and James D Watson as early as 1953 based upon the chemical and physical evidences known at that time. The structure shown in the figure looks like a twisted ladder. Two polynucleotide chain (strands) wind around each other an right handed turns as if two helices are intertwined and

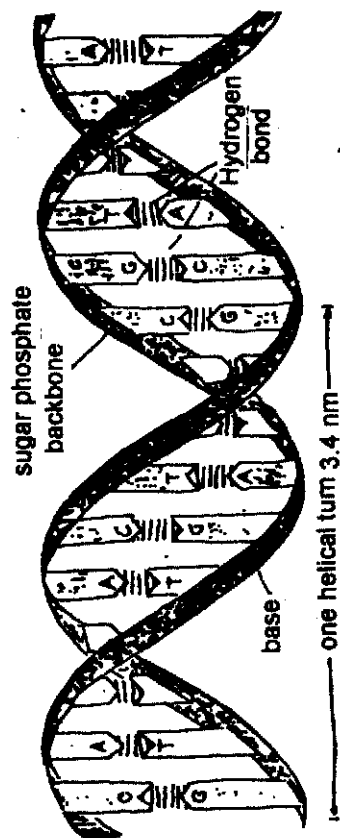


Fig. 34.6 Schematic diagram of a double helix

is called a right handed double helix. (Fig 34.6) The two sugar phosphate chains are held together by hydrogen bonds formed between a purine on one strand with a pyrimidine on the other. These are called Watson-Crick base pairs (see fig 34.7) and form the rungs of the twisted ladder. The nucleic acid chains have a sense of direction or polarity i.e. 3'-5' phosphodiester bonds are so oriented that all 3' bonds point to one direction and all 5'-bonds point to other. (see fig. 34.6) so that the chain has a 5' end and a 3' end. Conventionally the chain is always written in 5'-3' direction. In double helix structure, the two chains are anti parallel i.e. 5'-3' direction of the two chains are opposite. Guanine (G) on one strand always pairs with cytosine on the other strand and adenine (A) always pairs with thymine (T). This is known as complementarity rule of base-pairing which comes from experiments of E. Chargaff, who observed that whatever is the source of DNA, total amount of Purines always equalled to total amount of Pyrimidines i.e. $A+G=C+T$. The rungs (i.e. Watson-Crick base pair) in the three dimensional structure stack one upon another and form the inside core of the double helix and provide additional stability to the structure. The outside of the stack is covered by the sugar phosphate backbone carrying all the negative phosphate charges on the surface, which in solution attract positively charged cations like Na^+ , Mg^{++} etc. Such a double helix, of course, would have two grooves running parallelly, called major and minor grooves, through which the base pairs can be accessed.

Replication of DNA : The Watson-Crick double helix not only matches the known physical and chemical properties, it explains the long-standing biological mystery of how genetic information is inherited faithfully from parents to offspring. If DNA double helix is the genetic material and contains all the genetic information, the double helix needs to be faithfully copied (replicated) from the parental DNA to give two identical daughter helices, which can then be partitioned into two daughter cells when cell divides. Watson-Crick structure provides an easy answer. If the two strands are separated by breaking the hydrogen bonds, and each strand serves as a template for synthesis of the complementary strands the two daughter double helices thus generated will be identical (since G always pairs with C and A always pairs with T). This is known as semiconservative replication of DNA.

34.5.2 Structure of RNA

Unlike DNA, RNA is a single stranded molecule, which may fold back on itself to form a double helix structure by base pairing in a region where base sequences find complementary sequences. The folding region called a loop, contains unpaired bases and the double helical region is called a stem. In one RNA molecule several such stem-loop structures can form giving it a particular shape. (see fig. 34.8). Three principal kinds of RNA found in a cell are:

- Ribosomal RNA (rRNA):** It constitutes about 80% of total RNA in a cell and has a molecular mass about 100×10^4 . It is metabolically stable and is complexed with various proteins to form the structure called a ribosome. (an organelle structure within the cell where synthesis of protein molecules is carried out).
- Transfer RNA (t-RNA):** It is called soluble RNA and is of small molecular mass, about $2-5 \times 10^4$. t-RNA occurs in the cytoplasm and is about 15% of total RNA in the cell. It is involved in transporting amino acids to ribosomes. The stem loop structure of all tRNA has a particular shape called a clover leaf structure.

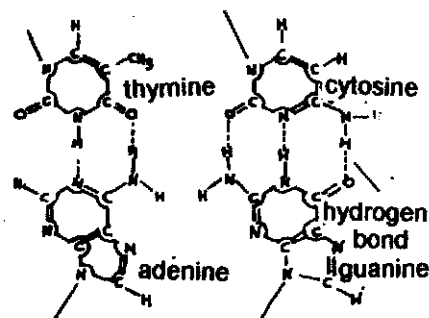


Fig. 34.7 Watson-Crick base pair

- c) **Messenger RNA (m-RNA):** This RNA also occurs in ribosomes, cytoplasm and nucleus. It constitutes about 5% of total RNA. Its molecular mass can vary and can go up to 50×10^4 or more. It has a short life and acts as a template for synthesis of proteins.

INTEXT QUESTIONS 34.2

1. What are the Watson-Crick base pairs?
.....
2. Why is DNA structure called a "double helix"? Who proposed this structure?
.....
3. Explain base complementarity with reference to DNA and RNA.
.....

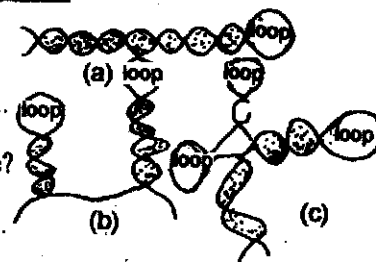


Fig. 34.8 Schematic representation of the RNA molecule showing stem-loop structure

34.6 FUNCTIONS OF DNA

DNA is regarded as the "master molecule" of living systems because of the key role it plays in living cells. The major functions played by DNA are :

- a) It contains all genetic information and its semi-conservative replication ensures that this information is passed on from one generation to next.
- b) It sends the information and instruction to the cell for synthesis of various proteins required by the cell. Information in DNA is first copied (transcribed) into RNA, which in turn is translated in the cell by ribosomes into proteins. This general scheme is known as *Central dogma of biology* i.e. $DNA \rightleftharpoons RNA \rightarrow \text{protein}$. When DNA is copied into DNA it is called *replication*, but when DNA is copied into RNA it is called *transcription*. RNA can also be copied into DNA, which is known as *reverse transcription*. Each copying work is carried out by a specific protein molecule, a polymerase enzyme.
- c) When exposed to penetrating radiations (UV, X-ray or γ -rays) or under action of certain chemicals DNA can get damaged or modified. If not corrected by the cell, these changes result in altered sequence in newly formed DNA during replication. This is known as *mutation*. Such mutations cause change in physiology and character of the animal and its offsprings since information on DNA is changed.

34.7 BIOLOGICAL FUNCTIONS OF RNA

RNAs are highly versatile class of molecules doing a wide range of biological functions. Besides the three major types, there are small nuclear or cytoplasmic RNAs doing important functions in the cell. The functions are given below:

- i) Main function of all three types of RNA is to take part in biosynthesis of proteins

- ii) Small nuclear RNA (SnRNA) carries out editing of m-RNAs in cells of higher organism e.g. mammals.
- iii) Cytoplasmic small RNA's combine with proteins forming ribonucleo protein complex called RNP particles. These particles carry or transport proteins through lipid membrane.
- iv) Some RNA molecules are component of some enzymes or act themselves as enzymes when they are known as ribozymes. Ribozymes specifically cuts or cleave another RNA by hydrolysis of phosphodiester bonds. The ribozymes have been created to inactivate RNA viruses which effects plants.

INTEXT QUESTIONS 34.3

1. What are the functions of DNA ?
.....
2. Write four biological functions of RNA.
.....

34.8 WHAT YOU HAVE LEARNT

- Nucleic acid is a phosphorus containing acidic substance from nuclei of pus cells. It is a long thread like molecule containing three distinct chemical constituents : phosphate group, pentose sugar and heterocyclic base.
- Two types of pertose sugar are found in nucleic acids; Deoxy-ribose and ribose
- The structure of DNA looks like a twisted ladder. Two polynucleotide chains wind around each other in right handed turns as if two helices are intertwined
- RNA is single stranded molecule, which may fold back on itself to form double helix structure by base pairing in a region where base sequences find complimentary sequence.
- DNA contains all genetic information
- Main functions of RNA is to take part in biosynthesis of proteins.

34.9 TERMINAL EXERCISE

1. What do you understand by the "central dogma" in biology?
.....
2. What is the difference between a Nucleoside and Nucleotide? Why nucleic acid is also called poly nucleotide?
.....

an nucleic acid molecule is made of three distinct chemical constituents. What are they?

- 4 What are different types of RNA found in living systems?

CHECK YOUR ANSWERS

ANSWER TO INTEXT QUESTIONS 34.1

- 1 Refer Section 34.4
- 2 Refer Section 34.4
- 3 Refer Section 34.4

ANSWERS TO INTEXT QUESTIONS 34.2

- In Watson-Crick double helical, structure, G always pairs with C through three hydrogen bonds and A always pairs with T through two hydrogen bonds. These particular hydrogen-bonded structures are called Watson-Crick base pairing.
2. Normal DNA structure is helical, but the helix is composed of two strands of DNA, that is why it is called "double helix" since two helical strands interwind to form the structure. This structure was proposed by J D Watson and Francis Crick in 1953.
 3. Refer section 34.5.1 and 34.5.2.

ANSWERS TO INTEXT QUESTIONS 34.3

- 1 Refer Section 34.6
- 2 Refer Section 34.7

ANSWERS TO TERMINAL EXERCISE

- 1 The "central dogma" of molecular biology is that genetic information which flows in the direction DNA-RNA-Protein i.e. DNA is first transcribed (copied) into RNA molecule, which is then translated into functional proteins. Certain viruses have RNA instead of DNA as their genome, which is first converted into DNA in the cell, so the central dogma is written now as



2. A nucleoside is composed of a heterocyclic base and a pentose sugar joined at the first carbon atom of the sugar with the N-atom of the base. When a phosphate group is attached to a nucleoside either at 5th or 3rd C-atom of the sugar unit it is called Nucleotide. Nucleic acid is called polynucleotide because basically it is a polymer formed by joining nucleotides.

The three distinct chemical constituents which make up the nucleic acid molecule are pentose sugar, phosphate group and four heterocyclic bases, two purines Adenine and Guanine and two pyrimidines among Cytosine, Thymine and Uracil

- 1 Refer Section 34.5.2