NUCLEIC ACIDS – STRUCTURE AND FUNCTION OF DNA AND RNA

Nucleic acids, particularly DNA, are the macromolecules considered to be the hereditary material which store the genetic information used in the development and functioning of all known living organisms. These universal molecules were first discovered by Friedrich Miescher in 1871. Nucleic acid structure is surprisingly simple, despite of its importance in cellular functions. There are two types of nucleic acids, Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA). The structure and functions of these molecules are described below:

Components

Nucleic acids are basically the polymer molecules of nucleotides which are essentially made up of three basic components, a heterocyclic nitrogenous base, a pentose sugar and a phosphate group.

Nitrogenous bases

Nitrogenous bases occurring in nucleic acids fall into two categories, viz., monocyclic bases (comprising of a hexagonal aromatic ring) called pyrimidines and bicyclic bases (comprising of one hexagonal and one pentagonal aromatic ring) called purines. They are polyfunctional bases having at least one N-H site for attaching with one organic substitute.

Purines (Fig. 1) are Adenine (A) and Guanine (G) and **Pyrimidines** (Fig. 2) are Cytosine (C), Thymine (T) and Uracil (U). The members of purines and pyrimidines share a similar structure, but differ in their side groups. Both of the nucleic acids i.e. DNA and RNA contain adenine, guanine and cytosine. However, thymine is found only in DNA and uracil only in RNA.

Purines

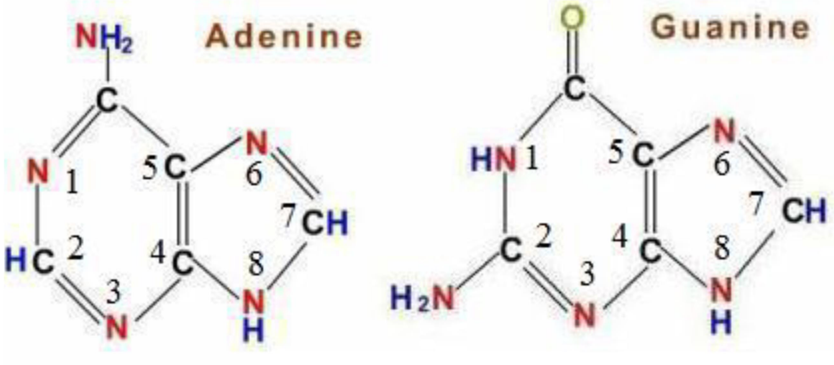

Figure 1. Structure of purines

Pyrimidines

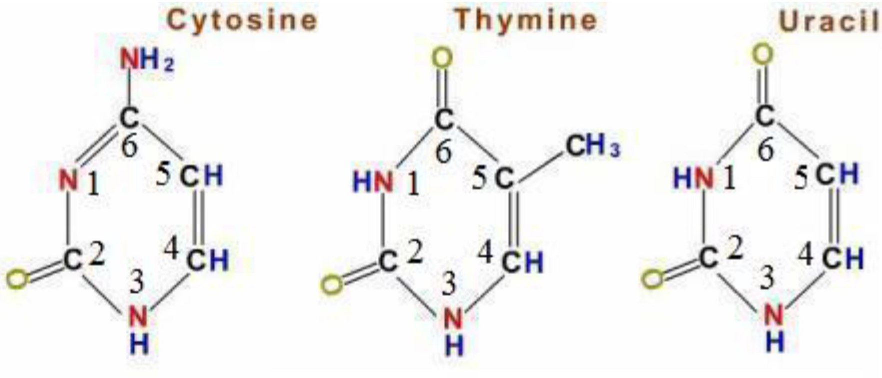

Figure 2. Structure of pyrimidine

Cyclic five carbon sugar

The Cyclic five carbon sugar present in Ribonucleic acid is ribose where as in Deoxyribonucleic acid it is 2' deoxyribose sugar

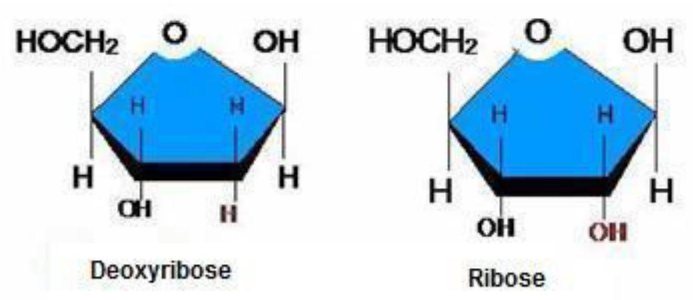

Figure 3. Structure of pentose sugar (Ribose/Deoxyribose)

Phosphoric acid
The phosphate group is attached to 5' carbon of pentose sugar molecule (Ribose/deoxyribose) by phosphodiester linkage. This group is responsible for the strong negative charge on both the nucleotides and nucleic acids.

Nucleoside
Nitrogenous base with a pentose sugar molecule (Ribose/deoxyribose) is known as Nucleoside. Nitrogen bases are attached to 1' carbon atom of the sugar by N-glycosidic bond

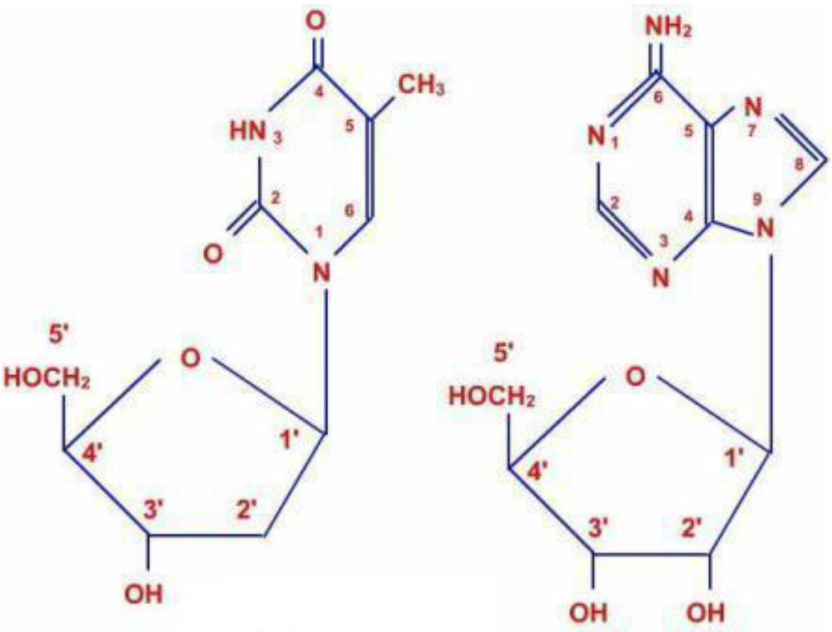

Figure 4. Structure of Nucleosides

Nucleotide

Nitrogenous base with ribose or deoxyribose sugar molecule and phosphate group is known as Nucleotide i.e. ribonucleotide (RNA) or deoxyribonucleotide (DNA) (Fig.5).

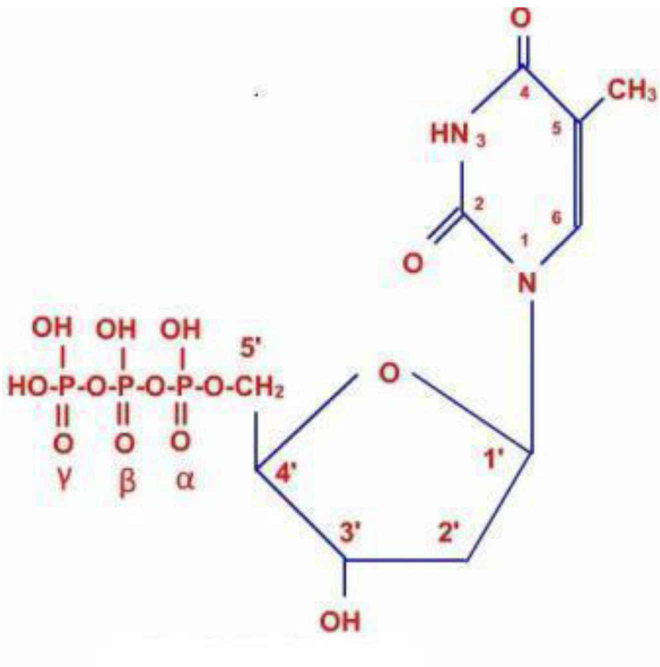

Fig. 5 Structure of Nucleotides

Deoxyribonucleic Acid (DNA)

The double helical structure of DNA was proposed by James Watson and Francis Crick in 1953 and nine years later, they along with Maurice Wilkins in 1962 received the Nobel Prize for this discovery.

DNA structure

The major role of DNA in a cell is to store the genetic information or instructions that are essential for carrying out various cellular functions like synthesis of biomolecules including RNA for the development of living cell. In prokaryotes, DNA is loosely packed in the cytoplasm and lacks distinct nuclear membrane. However, the cells of eukaryotic organisms contain DNA in their nucleus and in other organelles such as mitochondria or chloroplasts. DNA, in the form of plasmids, can also be located extrachromosomally both in prokaryotes and few eukaryotes such as yeast.

DNA consists of two polymer chains made up of nucleotides. These two long strands are intertwined (coiled) in the shape of a double helix which have the unique ability to wind and unwind to facilitate the duplication process. Each strand of polynucleotide consists of sugar-phosphate backbone made up of alternating 2′ deoxyribose and phosphate groups. The third carbon of 2′ deoxyribose sugar molecule is attached to the phosphate group by phosphodiester bond to the fifth carbon atom of adjacent 2′ deoxyribose molecule. Because of these asymmetric bonds, each DNA strand of the helix has a unique direction i.e. the direction of one strand is opposite to the other and thus two strands are antiparallel to each other. As a result, one DNA strand has 3′ end with terminal hydroxyl group and the second strand has 5′ end having a terminal phosphate group. Both chains are arranged in such a way that the nitrogenous bases, purine and pyrimidines, are inside the helix (variable) and the sugar-phosphate backbones are onnthe outside of the helix (constant) (Fig. 6).

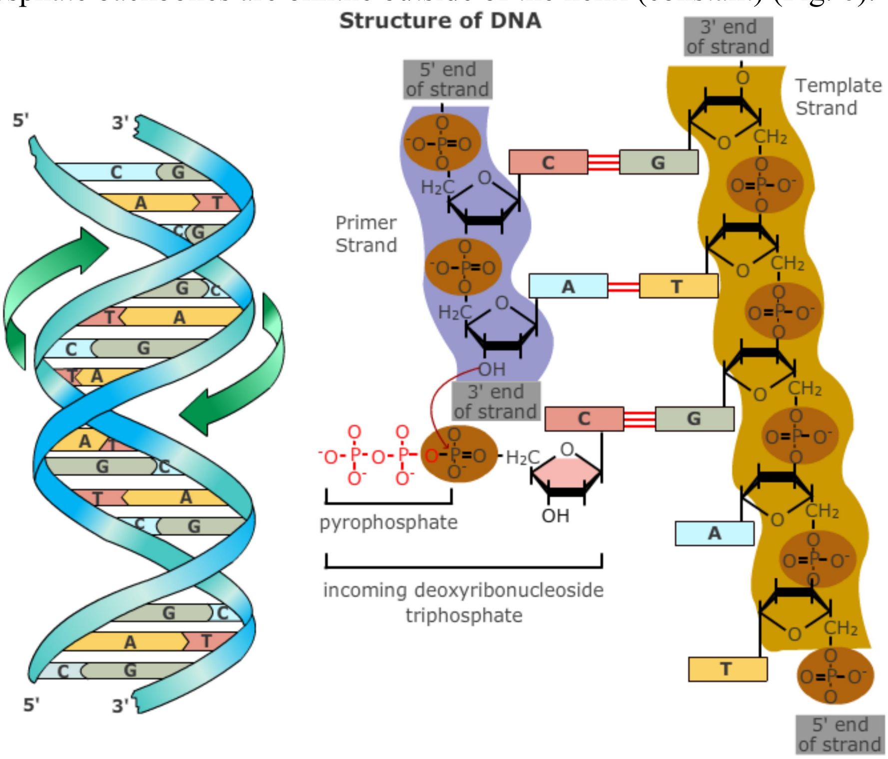

Fig. 6. The structure of DNA

Ribonucleic Acid
RNA is primarily a single stranded molecule containing purine and pyrimidine nitrogenous bases such as A, G, C and U and a ribose sugar. The major functions of RNA center around translating the genetic information contained in DNA into protein on ribosomal units. There are 3 types of RNA i.e. messenger RNA (mRNA), transfer RNA (tRNA) and ribosomal RNA (rRNA)

Messenger RNA (mRNA)
mRNA constitutes the functional part of DNA and thus plays an important role in protein synthesis.

Transfer RNA (tRNA)
tRNA molecules act as adapters which carry specific amino acids from the cytoplasm on to the ribosomes during synthesis of proteins.

Ribosomal RNA (rRNA)
Ribosomal ribonucleic acid (rRNA) is the RNA component of the ribosome, the site of protein synthesis in all living cells.

Differences between DNA and RNA Molecules
The major differences between DNA and RNA in respect of their location, structure and function are delineated in Figure 7
- Uracil base is available instead of thymine base, and Ribose sugar instead of Deoxyribose sugar.
-Unlike DNA, RNA contains -OH group in the 2 'position of the annular ribose sugar
- In DNA, there is no -OH group in the 2 'position.
- The genes in DNA are linked to the ribose group of the RNA molecule during the RNA chain is formation. However, in RNA, instead of thymine base, uracil base is present.

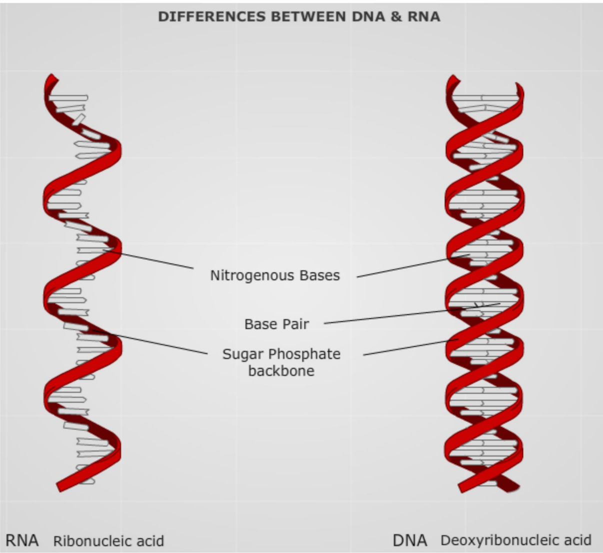

Figure 7. DNA vs. RNA

GENE EXPRESSION – TRANSCRIPTION AND TRANSLATION

Gene is defined as a specific nucleotide sequence encoding a particular function through synthesis of a protein. It represents the simplest hereditary unit in a cell which is associated with regulatory, transcriptional and other functional regions. In general these genes hold the information to build and maintain an organism's cells and pass genetic traits to offspring. All the metabolic functions in a cell are performed by expression of Genes. Gene expression is the process by which information from a gene is used in the synthesis of a functional gene product. These products are often proteins which can serve as the structural component of the cell and biological catalysts to facilitate cellular metabolic reactions. rRNA or tRNA constitute the non-protein component of the coding genes. The process of gene expression is used by prokaryotes, eukaryotes and viruses to generate the macromolecular machinery for life. The flow of hereditary information from genes to proteins is dictated by 'Central Dogma of Life'.

Central Dogma of Life

The central dogma of life was first visualized by Francis Crick during the year 1958 which refers to the fact that hereditary information normally travels in one direction only i.e. from DNA to DNA (replication) to RNA (transcription) and to Protein (translation) as shown in Fig.8. However, the reverse flow of information from RNA to DNA is also possible and the process is called Reverse Genetics.

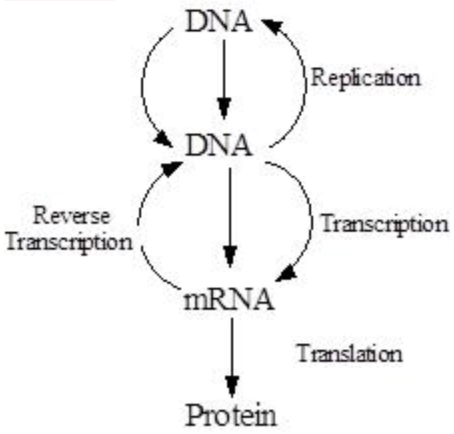

Fig. 8. Central dogma of life

The process of gene expression involves two major steps i.e. transcription and translation as defined below:

Transcription

Transcription is the process by which the genetic information from one strand of DNA is transferred to mRNA which is eventually used as template in the protein synthesis. This is the key step involved in gene expression. One of the DNA strands which provides information for synthesis of mRNA is called template or antisense or non-coding strand. The other strand that matches exactly with the mRNA is called coding strand or sense strand or non-template strand (Fig. 9).

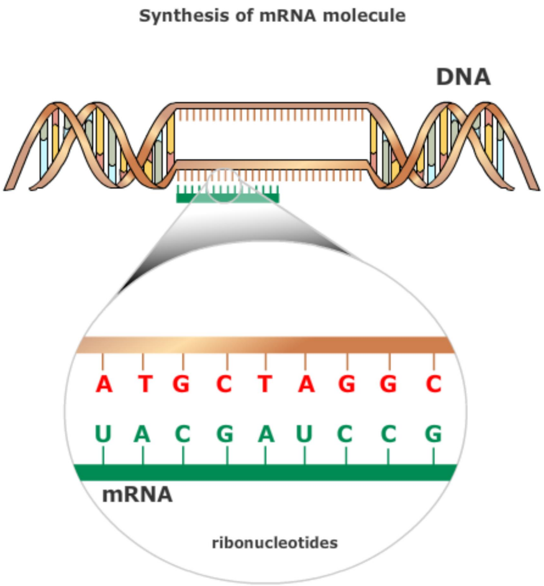

Figure 9. mRNA synthesis

Translation

Translation is the process of decoding the information contained in the form of codon sequences on mRNA and synthesizing a chain of amino acids which finally results into a protein molecule.

The function of tRNA is to transfer the appropriate amino acids from the cytoplasm to the new polypeptide chain, which is being constructed, on the ribosome.

Proper positioning of the mRNA is vital to determine its reading frame, which defines which group of three bases is to be read as codons. For example, **AUG UCC UGG** or **A UGU CCU GG**. Hence, the presence of a start codon AUG coding amino acid methionine signals beginning of genetic message. The translation initiation process is shown in Fig. 10

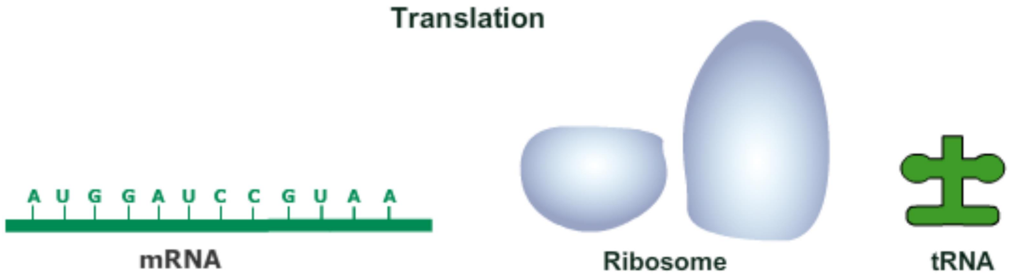

Fig.10. Translation initiation process