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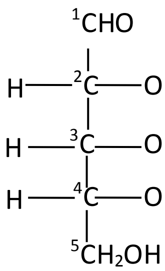
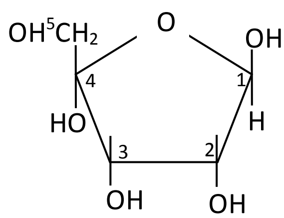
Structure and Properties of Nucleic Acids

Nucleic acids are polymers of nucleotides linked through phosphodiester linkages. Two types of nucleic acids; Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA) are present in the cell. Among these DNA act as a genetic material and inherit the information from one generation to next. RNA comprises of several types namely messenger RNA (mRNA), ribosomal RNA (rRNA) and transfer RNA (tRNA). RNA play many other roles like rRNA is component of ribosomes while mRNA contains codons that are translated into proteins. tRNA transfers corrects amino acid on the growing polypeptide chain by reading the codons of mRNA.

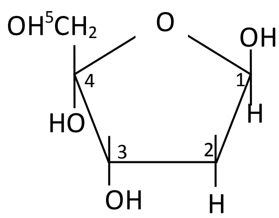
Nucleotides of DNA and RNA are made up of nitrogenous bases, sugar and phosphate. The sugar that is present in nucleic acids is pentose sugar which is of two types; one that present in DNA is 2-deoxy-D-ribose and the other present in RNA is D-ribose. Both the pentoses are present as closed five membered ring (β-furanose form) (Figure 1).



D-Ribose sugar (a pentose)



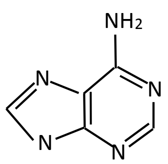
β-D-ribofuranose



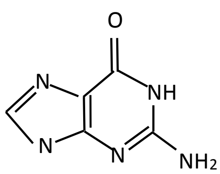
2-deoxy-D-ribofuranose

Figure 1: Structure of pentose sugars present in nucleic acids.

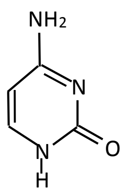
Nitrogenous bases are of two types; purines and pyrimidines. The two purine bases of DNA and RNA are adenine (A) and guanine (G). Among pyrimidines cytosine (C) is present in both DNA and RNA, thymine (T) is present in DNA only and uracil (U) is present in RNA only. The structure of five major bases is shown in (Figure 18). The purines and pyrimidens bases contain aromatic ring having conjugated double bonds structures which absorb light a wavelength near 260nm.



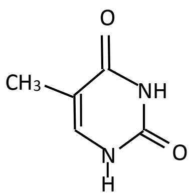
Adenine (A)



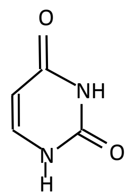
Guanine (G)



Cytosine (C)



Thymine (T)



Uracil (U)

Figure 1: Structure of nitrogenous bases present in nucleic acids.

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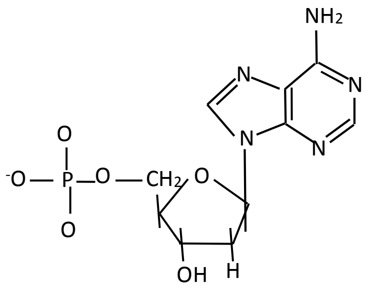
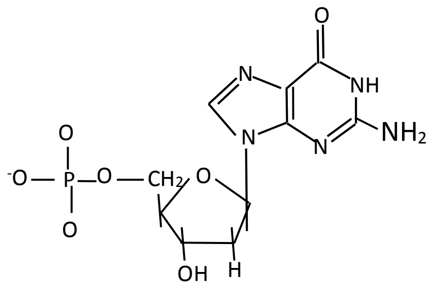
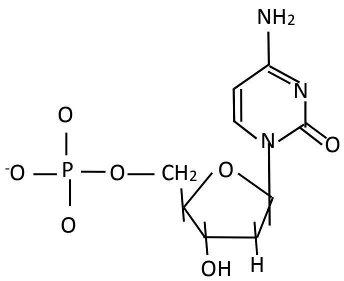
The bases, sugar and phosphate linked together to form nucleotide. N-9 (nitrogen 9) of purine bases form an N-β-glycosyl bond to the C-1 (carbon 1) of the pentoses while N-1 of pyrimidine bases form an N-β-glycosyl bond to the C-1 of the pentoses. A phosphate molecule is esterified to the 5´ carbon of the pentose. The nucleotides in DNA are called deoxyribonucleotides or deoxyribonucleosides-5´-monophosphates form the structural unit of DNA. They are of four types namely; deoxyadenylate (deoxyadenosine-5´-monophosphate)**,** deoxyguanylate (deoxyguanosine-5´-monophosphate), deoxycytidylate (deoxycytidine-5´-monophosphate) and deoxythymidylate (deoxythymine-5´-monophosphate) (Figure 2).



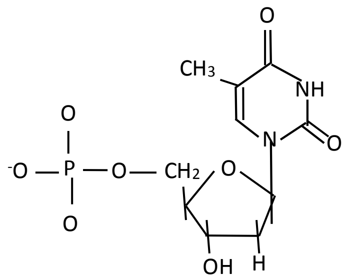
Deoxyadenylate (deoxyadenosine-5´-monophosphate)



Deoxyguanylate (deoxyguanosine-5´-monophosphate)



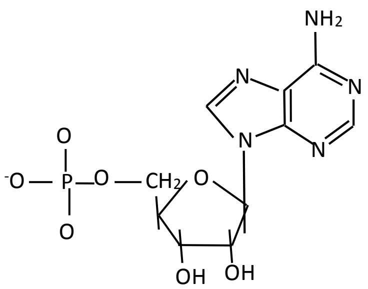
Deoxycytidylate (deoxycytidine-5´-monophosphate)



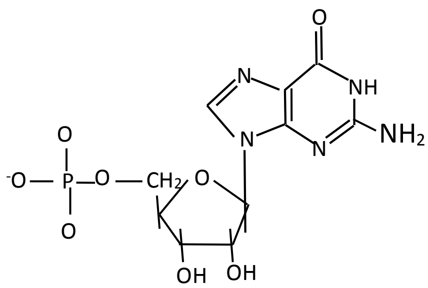
Deoxythymidylate (deoxythymine-5´-monophosphate)

Figure 2: The nucleotides present in DNA.

The nucleotides in RNA are called ribonucleotides or ribonucleotide-5´- monophosphate and are the structural units of RNA. There are four types of ribonucleotides namely; adenylate (adenosine-5´-monophosphate), guanylate (guanine-5´-monophosphate), cytidylate (cytidine-5´-monophosphate) and uridylate (uridine-5´-monophosphate) (Figure 3).



Adenylate (adenosine-5´-monophosphate)



Guanylate (guanine-5´-monophosphate)

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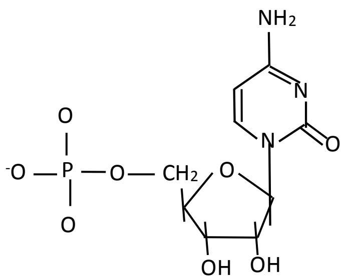
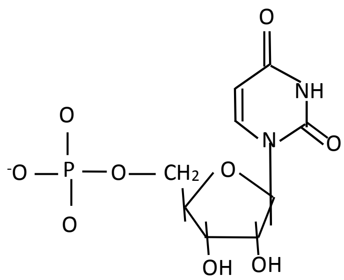


Cytidylate (cytidine-5´-monophosphate)



Uridylate (uridine-5´-monophosphate)

Figure 3: The nucleotides present in RNA.

Primary structure of nucleic acids

Nucleotides of both DNA and RNA are covalently linked by phosphate group in which the 5′-phosphate group of one nucleotide unit is attached to the 3′ hydroxyl group of the next nucleotide, forming a phosphodiester linkage. Thus the alternating phosphate and pentose residues form the covalent backbones and nitrogenous bases form side groups joined to the backbone at regular intervals (Figure 4). The backbone of both DNA and RNA are hydrophilic as –OH groups of sugar residues form hydrogen bonds with water. All ends of linear 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 of ribose. The covalent backbone of RNA is hydrolyzed rapidly in alkaline condition. The 2′-OH group acts nucleophilically on adjacent phosphate group thus hydrolyzing the RNA backbone. Since DNA backbone lacks 2′-OH, it is stable under similar conditions.

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(A.) Primary structure of DNA (B.) Primary structure of RNA

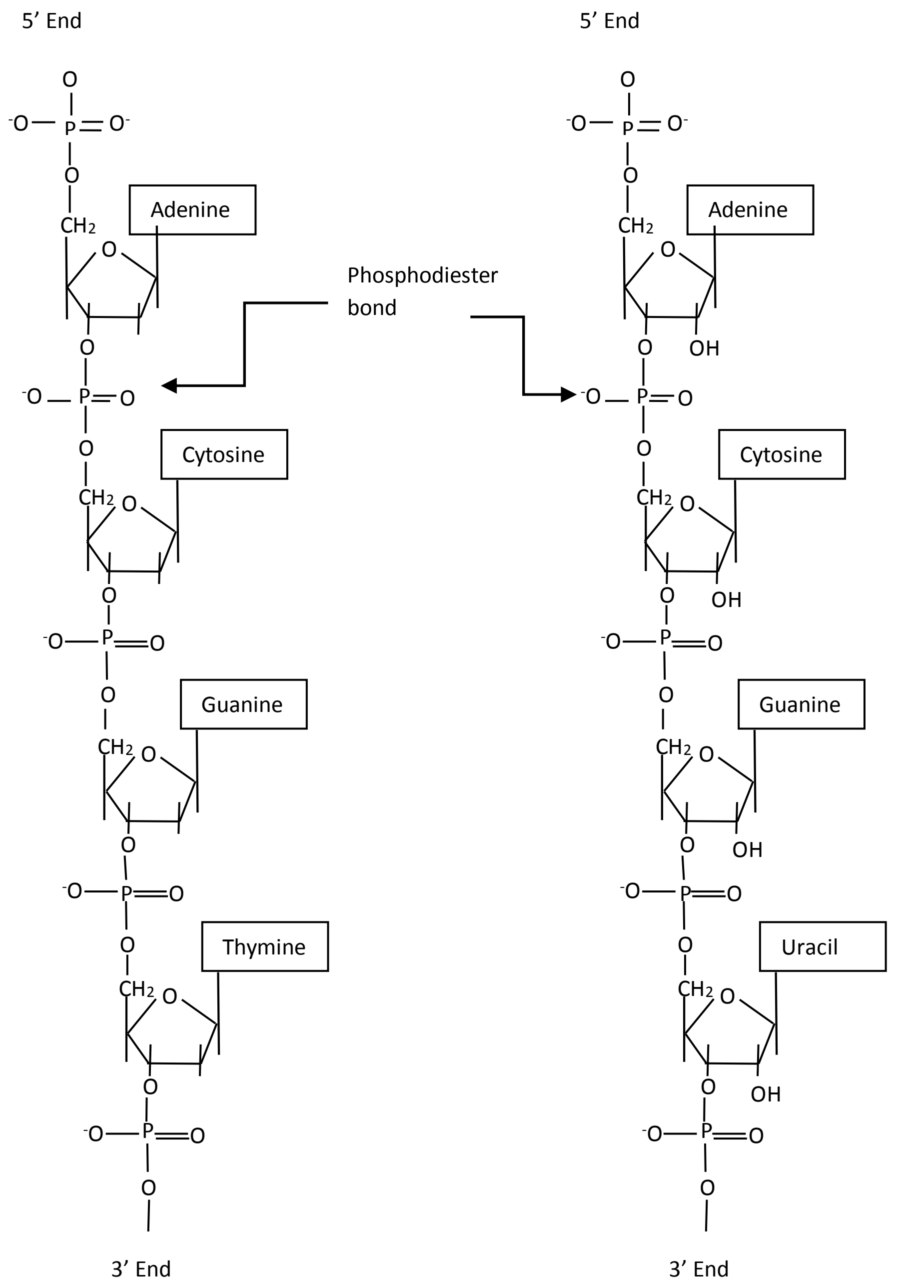

Figure 4: Primary structure of DNA (A.) and RNA (B.).

The polynucleotide of upto 50 nucleotides is referred as an oligonucleotide. A larger nucleic acid is called as polynucleotide.

Secondary structure of DNA

James Watson and Francis Crick in 1953 described the three dimensional structure of DNA. It consists of two polynucleotide chains of DNA wound around the same axis to form right handed double helix

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(Figure 5). The two strands are oriented antiparallel i.e. their 3′ and 5′ phosphodiester bonds run in opposite directions. The sugar and phosphate backbone forms the outer circumference of the double helix therefore exposed to polar environment having water. The bases of both the strands are stacked inside the core of the helix makes it hydrophobic. The rings of bases are planer and perpendicular to the helix axis. The surface of DNA double helix has two grooves, one is called major groove and other is minor groove. Within the helix each nucleotide base of one strand makes hydrogen bonds in the same plane with a base of the other strand. A of one strand forms two hydrogen bonds with T of the other strand and vice versa and G on the one strand forms three hydrogen bonds with Con the other strand vice versa. So two hydrogen bonds can form between A=T and T=A, and three hydrogen bonds can form between G≡C and C≡G. Because of these three hydrogen bonds separation of DNA helices needs more energy when ratio of GC to AT bp is higher.

The two antiparallel polynucleotide chains of DNA helix are not identical but they are complementary to each other. Whenever A occurs in one strand, T will be present in the other strand and vice versa similarly whenever G occurs in one chain, C will be present in the other strand and vice versa. The distance between the stacked bases double helix is 3.4 A°. The distance for making one complete helix turn is 34 A°. The number of base pairs in each complete turn of double helix is 10.5.The double helix of DNA is held together by two forces. One is hydrogen bonding between the complementary bases pairs and second is the base stacking interaction.

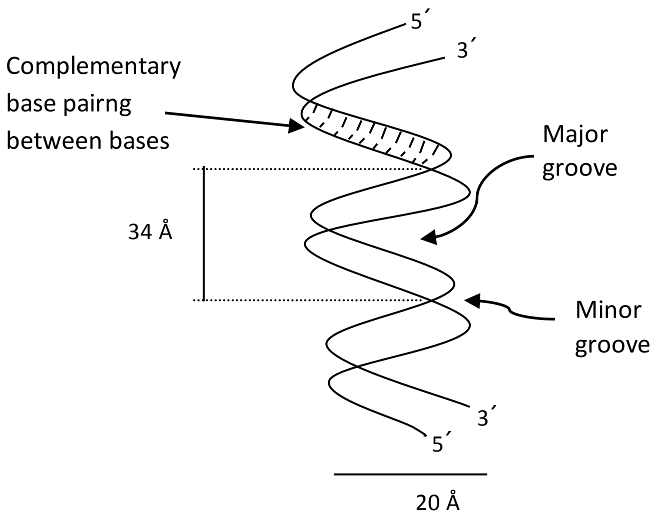

Figure 5: Double helical structure of DNA.

The Watson-Crick structure of DNA is also known as B-DNA. There are few deviations from Watson-Crick DNA double helix structures. The B-DNA is the most stable form of DNA. The two other structural variations are A-DNA and Z-DNA. A-DNA occurs in solutions that are devoid of water. A-DNA is right handed double helix. Helix is wider and numbers of base pairs per helix are 11. Z-DNA is left handed helix and occur when DNA strands contain alternatively G and C repeats. The surface of helix is zigzag. It is more slender and elongated having 12 base pairs per turn.

mRNA

Whereas DNA contain genetic information, RNA act as an intermediary by using the information coded in DNA to specify amino acid sequence of a protein. DNA is present in nucleus and protein synthesis takes place on ribosomes in cytosol. mRNA carries the message from DNA to protein synthesizing machinery of the ribosome which is present in the cytosol. mRNA is synthesized from DNA through a process known as transcription. mRNA provides template that specify amino acid sequences in polypeptide chains.

rRNA

rRNA are components of ribosomes. The prokaryotic ribosome is made up of two subunits; small subunit is called 30S subunit and 50S subunit. Small subunit contain 16SrRNA while large subunit contain 23SrRNA and 5S rRNA. Eukaryotic ribosomes are made up of small (40S) and large (60S) subunits. Small subunit contain 18S rRNA while large subunit contain 28S rRNA, 5.8S rRNA. RNA can base pair with complementary regions of either RNA or DNA. G base pairs with C and A base pairs with U. The paired strands in RNA-RNA or RNA-DNA duplexes are antiparallel. The three dimensional structures of many RNAs include weak interactions like base-stacking interactions which stabilize its structure. The RNA double strands are not perfectly complementary. Unlike DNA which has B-form helix RNA attain A-form of helix. RNA helix contain breaks caused by mismatch or unmatched bases in one or both the strands which result in bulges or internal loops. Hairpin loops are also formed between nearby self complementary sequences.

tRNA

tRNA are the small RNA which function as adapter molecules during protein synthesis. Amino acids are linked covalently at one end while its other end base pair with mRNA. Secondary structure of tRNA is clover leaf structure made up of four stem loop structure. The aminoacyl stem attaches its cognate amino acid covalently, the D arm contain the modified base dihydrouridine, the antcodon arm contain the three anticodons which base pair with the codons on the mRNA, and the TC are which contain modified base pseudouridine. the three dimensional structure of tRNA is L-shaped structure in which one leg of the L is formed by acceptor and T stems folded into a continuous A form of double helix. The other leg is composed of D arm and the anticodon arm. About 25% bases of tRNA are modified or hypermodified.