# Fundamentals of Organic Chemistry

## CHEM 109

*For Students of Health Colleges*

Credit hrs.: (2+1)

*King Saud University*

College of Science, Chemistry Department

CHAPTER 10: Nucleic Acids

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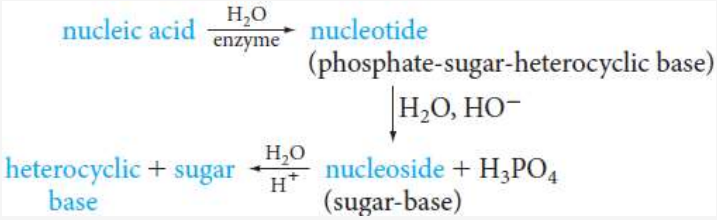
## The General Structure of Nucleic Acids

- *Nucleic acids* are molecules that allow organisms to transfer genetic information from one generation to the next.
- *Nucleic acids*, are linear polymers (chains) made out of units called nucleotides.
- Hydrolysis of nucleic acids gives nucleotides, which are the building blocks of nucleic acids.

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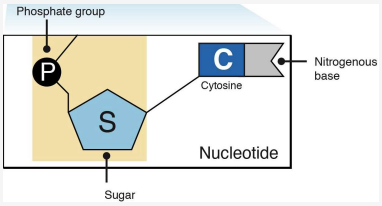
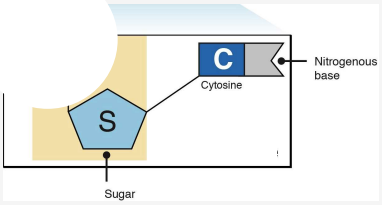
## The General Structure of Nucleic Acids

- *Nucleotides :* contain three parts:
  - A Nitrogenous Base (Nucleobase)
  - A Five-Carbon Sugar (Pentose)
  - A Phosphate Group




- *Nucleosides :* contain two parts:
  - A Nitrogenous Base (Nucleobase)
  - A Five-Carbon Sugar (Pentose)

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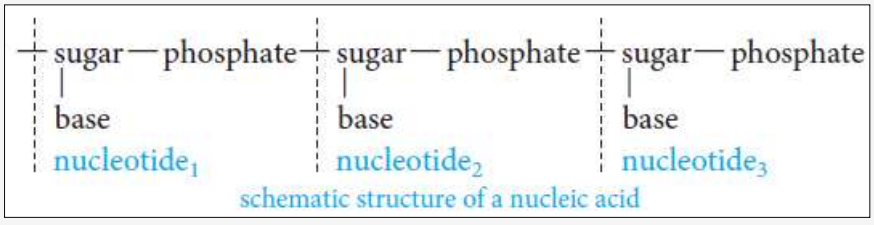
## The General Structure of Nucleic Acids

- The overall structure of the nucleic acid is a macromolecule with a backbone of sugar molecules connected by phosphate links and with a base attached to each sugar unit.




schematic structure of a nucleic acid

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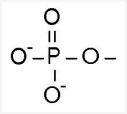
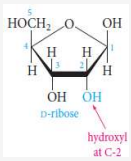
# The General Structure of Nucleic Acids

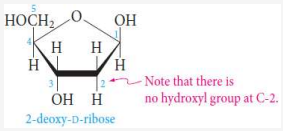
## Phosphate group



## Pentose Sugar

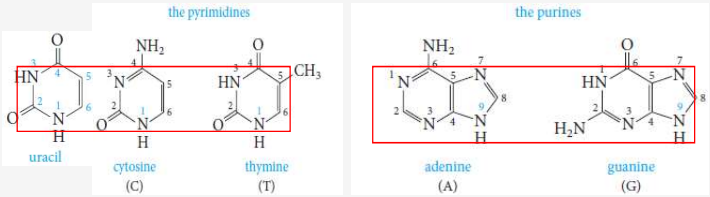
- Ribonucleic acid (RNA) contains the pentose ribose.
- Deoxyribonucleic acid (DNA) contains the pentose deoxyribose.




## Heterocyclic Base

The sugars also contain a pyrimidine or purine base present on the 1-carbon replacing the hydroxyl group with a base.

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# The General Structure of Nucleic Acids

## Differences Between DNA and RNA Composition

| | DNA | RNA |
|---|---|---|
| Five-Carbon Sugar | Deoxyribose | Ribose |
| Nitrogenous Bases | Adenine, Guanine, Cytosine, and Thymine or methyluracil | Adenine, Guanine, Cytosine, and Uracil |

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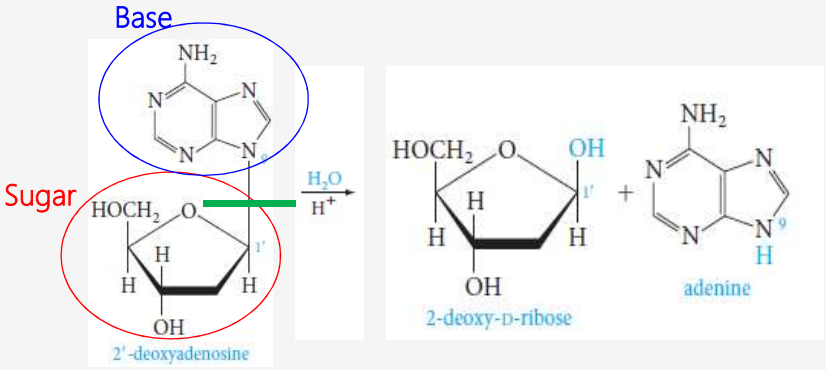
## The General Structure of Nucleic Acids

- Nucleoside

*The combination of the pentose sugar and a purine or pyrimidine base.*

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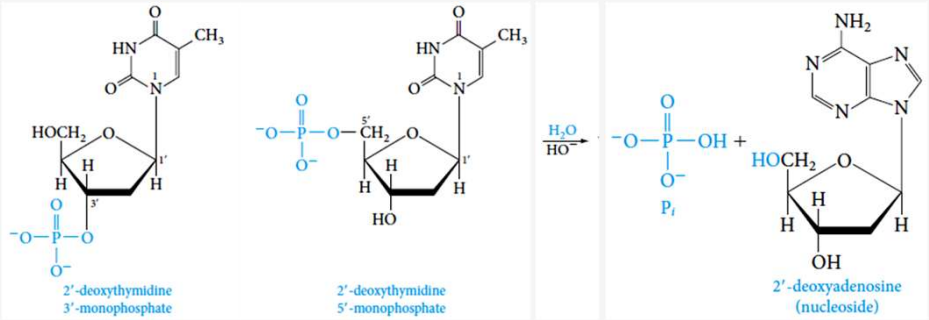
## The General Structure of Nucleic Acids

- Nucleotides are phosphate esters of nucleosides.

  *A hydroxyl group in the sugar part of a nucleoside is esterified with phosphoric acid.*

  *In DNA nucleotides, either the 3′ or the 5′ hydroxyl group of 2-deoxy-d-ribose is esterified.*

- Nucleotides can be hydrolyzed by aqueous base (or by enzymes) to nucleosides and phosphoric acid.

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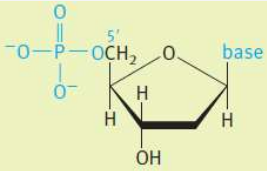
## The General Structure of Nucleic Acids

- In these abbreviations, letter d stands for 2-deoxy-d-ribose, the next letter refers to the heterocyclic base, and MP stands for monophosphate.




| Base | Monophosphate name | Abbreviation |
|---|---|---|
| cytosine (C) | 2′-deoxycytidine 5′-monophosphate | dCMP |
| thymine (T) | 2′-deoxythymidine 5′-monophosphate | dTMP |
| adenine (A) | 2′-deoxyadenosine 5′-monophosphate | dAMP |
| guanine (G) | 2′-deoxyguanosine 5′-monophosphate | dGMP |

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## The General Structure of Nucleic Acids

- Nucleic acids are polynucleotides attached by the phosphate moieties through the 3′ and 5′ sites on the pentose.
- The name nucleic acid is derived from the fact that they are acidic, containing a phosphoric acid moiety, and are found in the nuclei of cells.
- Pure nucleic acid was isolated by Levene in the early 1900s.
- He showed that either D-ribose or D-deoxyribose was present in what are now known as ribonucleic acid (RNA) and deoxyribonucleic acid (DNA).
- There are two major types of nucleic acids:
  - Deoxyribonucleic acid (DNA)
  - Ribonucleic acid (RNA).

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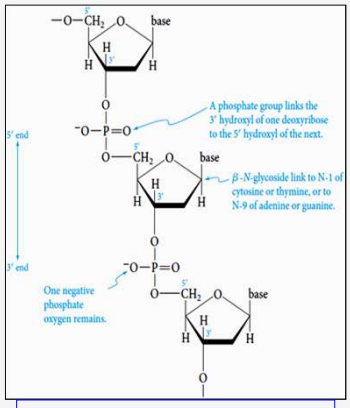
## The Primary Structure of DNA

**Deoxyribonucleic Acid (DNA)**

- In DNA, 2-deoxy-d-ribose and phosphate units alternate in the backbone.
- The 3′ hydroxyl of one ribose unit is linked to the 5′ hydroxyl of the next ribose unit by a phosphodiester bond.
- The heterocyclic base is connected to the anomeric carbon of each deoxyribose unit by a *β*-*N*-glycosidic bond.
- In DNA, there are no remaining hydroxyl groups on any deoxyribose unit.
- Each phosphate, however, still has one acidic proton that is usually ionized at pH 7, leaving a negatively charged oxygen.
- A complete description of any particular DNA molecule, which may contain thousands or even millions of nucleotide units, would have to include the exact sequence of heterocyclic bases (A, C, G, and T) along the chain.




A segment of a DNA chain

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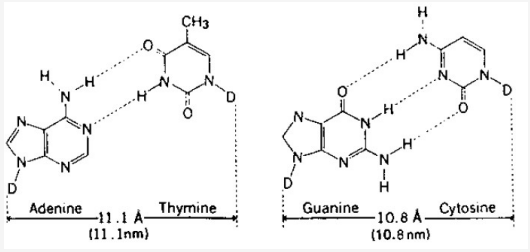
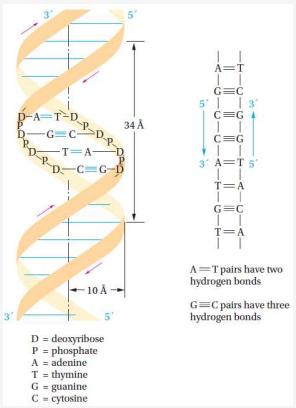
## Secondary DNA Structure; the Double Helix

**Deoxyribonucleic Acid (DNA)**




Two hydrogen bonds Three hydrogen bonds




Model and schematic representations of the DNA double helix.
The space-filling model at the left shows the base pairs in the helix interior, in planes perpendicular to the main helical axis. The center drawing shows the structure more schematically, including the dimensions of the double helix. At the far right is a schematic method for showing base pairing in the two strands.

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## Secondary DNA Structure; the Double Helix

## Deoxyribonucleic Acid (DNA)

- In 1953, when Watson and Crick, working together in Cambridge, England, proposed the double helix model for DNA.
- **The important features of their model follow:**

1. DNA consists of two helical polynucleotide chains coiled around a common axis.
2. The helices are right-handed, and the two strands run in opposite directions with regard to their 3′ and 5′ ends.
3. The purine and pyrimidine bases lie *inside* the helix, in planes perpendicular to the helical axis; the deoxyribose and phosphate groups form the outside of the helix.
4. The two chains are held together by;
   - *Purine–pyrimidine base pairs* connected by hydrogen bonds.
     - *Adenine is always paired with thymine, and*
     - *Guanine is always paired with cytosine.*
5. The diameter of the helix is 20 A.

   Adjacent base pairs are separated by 3.4 A and oriented through a helical rotation of 36°.

   There are therefore 10 base pairs for every turn of the helix (360°), and the structure repeats every 34 A.
6. There is no restriction on the sequence of bases along a polynucleotide chain. The exact sequence carries the genetic information.

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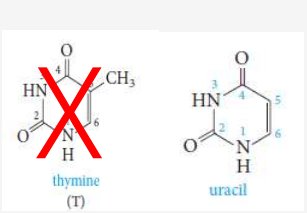
## Ribonucleic Acid (RNA)

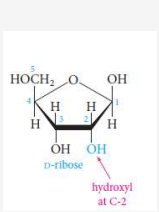
- Ribonucleic acids (RNA) differ from DNA in three important ways:

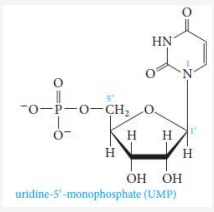
(1) The sugar is D-ribose;

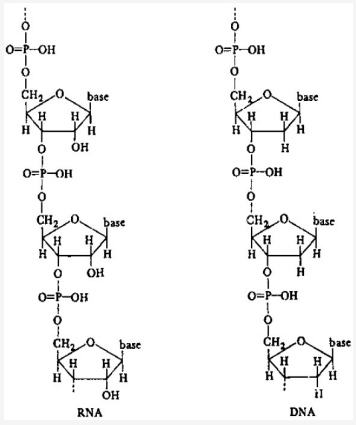
(2) Uracil replaces thymine as one of the four heterocyclic bases

(3) Many RNAs are
- Single-stranded segments,
- Combinations of complementary two-stranded helices,
- Complex structures.

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# Ribonucleic Acid (RNA)

- The transcription product of DNA is always single-stranded RNA.
- The single strand generally assumes a right-handed helical conformation mainly caused by base-stacking interactions also present in the DNA.
- The order of interaction is purine-purine >> purine-pyrimidine > pyrimidine-pyrimidine.
- For coupled RNA the two strands are antiparallel as in DNA.

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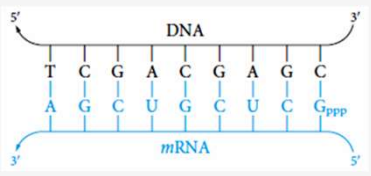
# Ribonucleic Acid (RNA)

Cells contain three major types of RNA.

## 1) Messenger RNA (mRNA)

- mRNA, size from about 75 units to over 3000 nucleotide units giving a molecular weight of 25,000 to one million.
- It is present at a percentage of about 5% of the total RNA in a cell.
- mRNA is involved in transcription of the genetic code and is the template for protein synthesis.
- There is a specific mRNA for every protein synthesized by the cell.
- The base sequence of mRNA is complementary to the base sequence in a single strand of DNA, with U replacing T as the complement of A.

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# Ribonucleic Acid (RNA)

## 2) Transfer RNA (tRNA)

- tRNA has about 73–94 nucleotides with a corresponding molecular weight range of 23,000–30,000.
- It is present in the cell at a level of about 15%.
- tRNA carries amino acids in an activated form to the ribosome for peptide bond formation, in a sequence determined by the mRNA template.
- Each tRNA has a three-base sequence, C-C-A, at the 3' hydroxyl end, where the amino acid is attached as an ester.

## 3) Ribosomal RNA (rRNA)

- It comprises about 80% of the total cellular RNA (tRNA = 15%, mRNA = 5%) and is the main component of the ribosomes.
- Its molecular weight is large, and each molecule may contain several thousand nucleotide units.
- rRNA is a part of the protein synthesizing machinery of cells, ribosomes.

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