# Course: Fundamentals of Biochemistry
# Unit: 2

## TOPICS

Nucleic Acids: Structure
Purines and pyrimidines
Nucleosides & Nucleotides

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# BIOMOLECULES: THE MOLECULES OF LIFE

A biomolecule is an organic molecule produced by living organisms. Biomolecules act as building blocks of life and perform vital functions in living organisms.

## ELEMENTS IN BIOMOLECULES

More than 25 naturally occurring elements are found in biomolecules.

C Carbon | H Hydrogen | O Oxygen | N Nitrogen | P Phosphorus | S Sulfur

Four most abundant elements in living organisms (by % of total atoms):

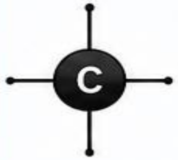
| | | |
|---|---|---|
| H | Hydrogen | ~62% |
| O | Oxygen | ~24.5% |
| N | Nitrogen | ~9.5% |
| C | Carbon | ~3% |

Together make up >99% of the mass of most cells.

## THE CENTRAL ROLE OF CARBON

Nearly all biomolecules are carbon compounds.

**Carbon's ability to form four covalent bonds with other elements allows the formation of a vast variety of complex molecules.**

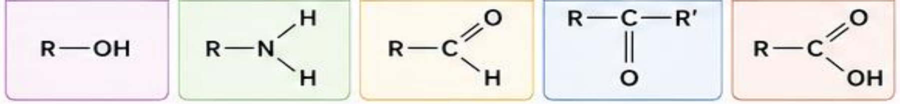



Examples of carbon skeletons


## FUNCTIONAL GROUPS

Biomolecules are often classified by their functional groups, which determine their chemical properties.

| Alcohols | Amines | Aldehydes | Ketones | Carboxylic acids |
|---|---|---|---|---|
| $-OH$ | $-NH_2$ | $-CHO$ | $>C=O$ | $-COOH$ |

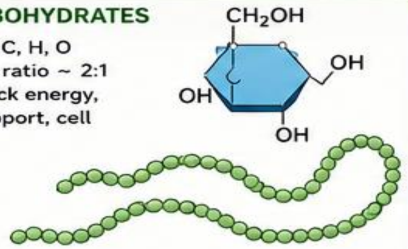



Many biomolecules are polyfunctional, containing two or more different kinds of functional groups.

## THE FOUR MAJOR FAMILIES OF BIOMOLECULES

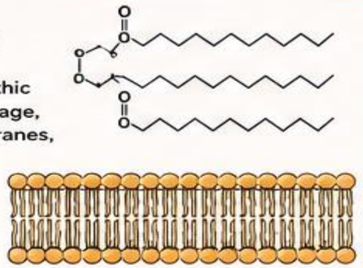
### 1. CARBOHYDRATES

Composed of C, H, O
Usually (H:O) ratio ~ 2:1
Function: Quick energy, structural support, cell recognition
Examples:
- Sugars
- Starch
- Cellulose
- Glycogen




### 2. LIPIDS

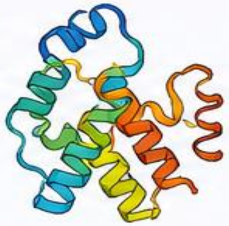
Composed of C, H, O (less O)
Nonpolar or amphipathic
Function: Energy storage, insulation, cell membranes, hormones
Examples:
- Fats/Oils
- Phospholipids
- Steroids



### 3. PROTEINS

Composed of C, H, O, N (Usually also S)
Monomers: Amino acids
Function: Enzymes, structure, transport, movement, defense, signaling

Example: Enzyme



### 4. NUCLEIC ACIDS

Composed of C, H, O, N, P
Monomers: Nucleotides
Function: Store, transmit and express genetic information

Examples:
- DNA (Deoxyribonucleic acid)
- RNA (Ribonucleic acid)

## SMALL BIOMOLECULES vs MACROMOLECULES

### Small Biomolecules

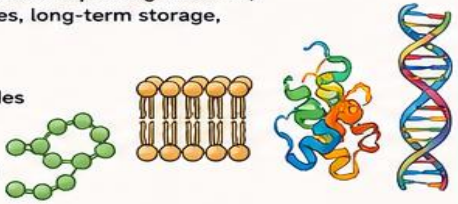
- Low molecular weight
- Soluble
- Not polymers
- Provide immediate energy and act as building blocks

**Examples:**
- Sugars
- Fatty acids
- Amino acids
- Nucleotides

### Macromolecules

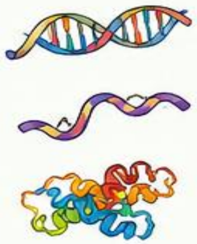
- High molecular weight
- Often insoluble
- Polymers (made of repeating subunits)
- Structural roles, long-term storage, catalysis

**Examples:**
- Polysaccharides
- Fats/Lipids
- Proteins
- Nucleic acids



## INFORMATIONAL MACROMOLECULES AND THEIR FUNCTIONS

### NUCLEIC ACIDS (DNA & RNA)



DNA (stores information)
↓
RNA (transcripts information)
↓
Protein (translates information)

### POLYSACCHARIDES (SUGARS)

- Energy storage (e.g., starch, glycogen)
- Structural support (e.g., cellulose in plant cell walls, chitin in exoskeletons)

### MAJOR FUNCTIONS OF BIOMOLECULES


**SUMMARY:** Biomolecules are essential organic compounds made primarily of C, H, O, N (and often P, S). They include four major families—carbohydrates, lipids, proteins, and nucleic acids—each with unique structures and functions. Small biomolecules serve as building blocks and immediate energy sources, while macromolecules (polymers) perform complex structural and functional roles in living organisms.

**Content Source: Lifesciences (fundamental & Practice by pranav kumar and usha mima)**

A *biomolecule* is an organic molecule that is produced by a living organism. Biomolecules act as building blocks of life and perform important functions in living organisms. More than 25 naturally occurring chemical elements are found in biomolecules. Most of the elements have relatively low atomic numbers. Biomolecules consist primarily of carbon, hydrogen, nitrogen, oxygen, phosphorus and sulfur. The four most abundant elements in living organisms, in terms of the percentage of the total number of atoms, are hydrogen, oxygen, nitrogen, and carbon, which together make up over 99% of the mass of most cells.

Nearly all of the biomolecules in a cell are carbon compounds, which account for more than one-half of the dry weight of the cells. Covalent bonding between carbon and other elements permit formation of a large number of compounds. Most biomolecules can be regarded as derivatives of hydrocarbons. The hydrogen atoms may be replaced by a variety of functional groups to yield different families of organic compounds. Typical families of organic compounds are the alcohols, which have one or more hydroxyl groups; amines, which have amino groups; aldehydes and ketones, which have carbonyl groups; and carboxylic acids, which have carboxyl groups. Many biomolecules are polyfunctional, containing two or more different kinds of functional groups. Functional groups determine chemical properties of biomolecules.

Sugars, fatty acids, amino acids and nucleotides constitute the four major families of biomolecules in cells. Many of the biomolecules found within cells are macromolecules and mostly are polymers (composed of small, covalently linked monomeric subunits). These macromolecules are proteins, carbohydrates, lipids and nucleic acids.

| *Small biomolecules* | *Macromolecules* |
|---|---|
| Sugars | Polysaccharide |
| Fatty acids | Fats/Lipids |
| Amino acids | Proteins |
| Nucleotide | Nucleic acid |

Nucleic acids and proteins are informational macromolecules. Proteins are polymers of amino acids and constitute the largest fraction (besides water) of cells. The nucleic acids, DNA and RNA, are polymers of nucleotides. They store, transmit, and translate genetic information. The polysaccharides, polymers of simple sugars, have two major functions. They serve as energy-yielding fuel stores and as extracellular structural elements.

# NUCLEIC ACIDS (DNA/RNA)

- In 1869, Friedrich Miescher discovered Nucleic Acids
- He found it in a cellular substance from nuclei of pus cells
- He named it Nuclein
- Nuclein showed acidic properties hence it got renamed as Nucleic Acid

*phosphate groups present in nucleic acids release hydrogen ions ($H^+$) in solution*

## What are Nucleic Acids?

Nucleic acids are **large biological macromolecules (biopolymers)** that are essential for life because they **store, transmit, and express genetic information**.

They are composed of repeating units called **nucleotides**, which are linked together to form long chains known as **polynucleotides**.
Every living organism—from bacteria to humans—contains nucleic acids.

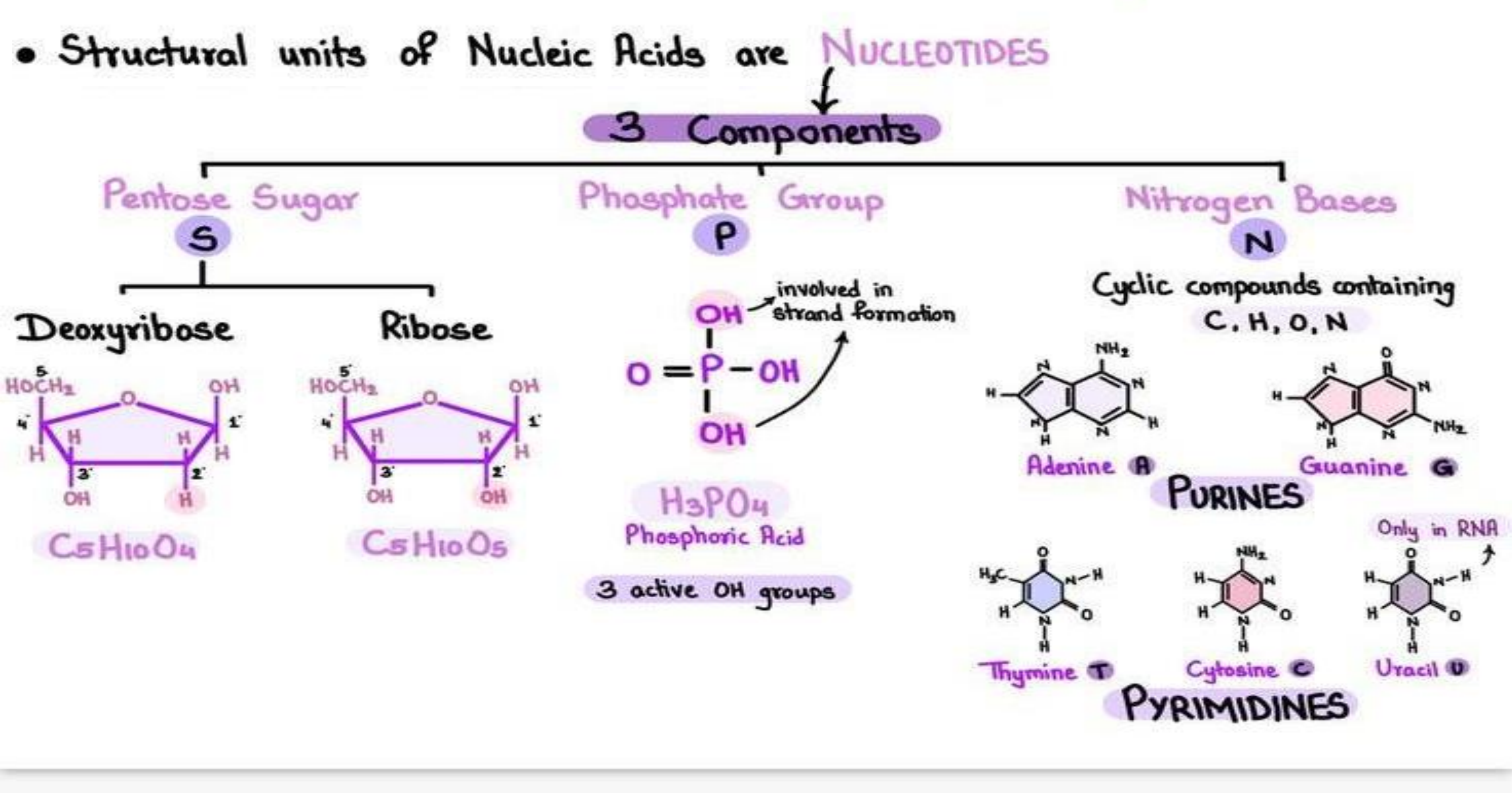
- Offsprings inherit genes from their parents

genes → DNA → Deoxyribonucleic acid

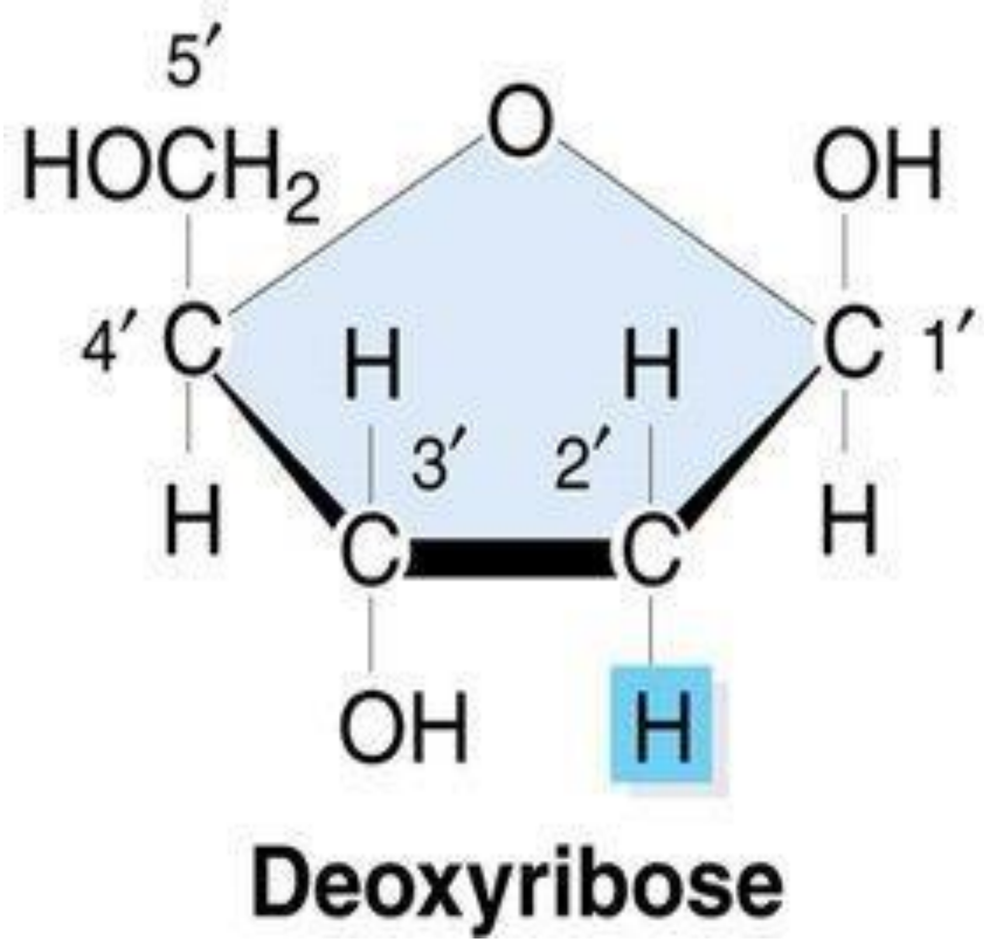
- Nucleic acids are polymers of Nucleotides
- 2 types of Nucleic acids ⟶ DNA & RNA → Ribonucleic acid
- Genetic material: DNA ⟶ Mostly in all living organisms

  RNA ⟶ In Viruses

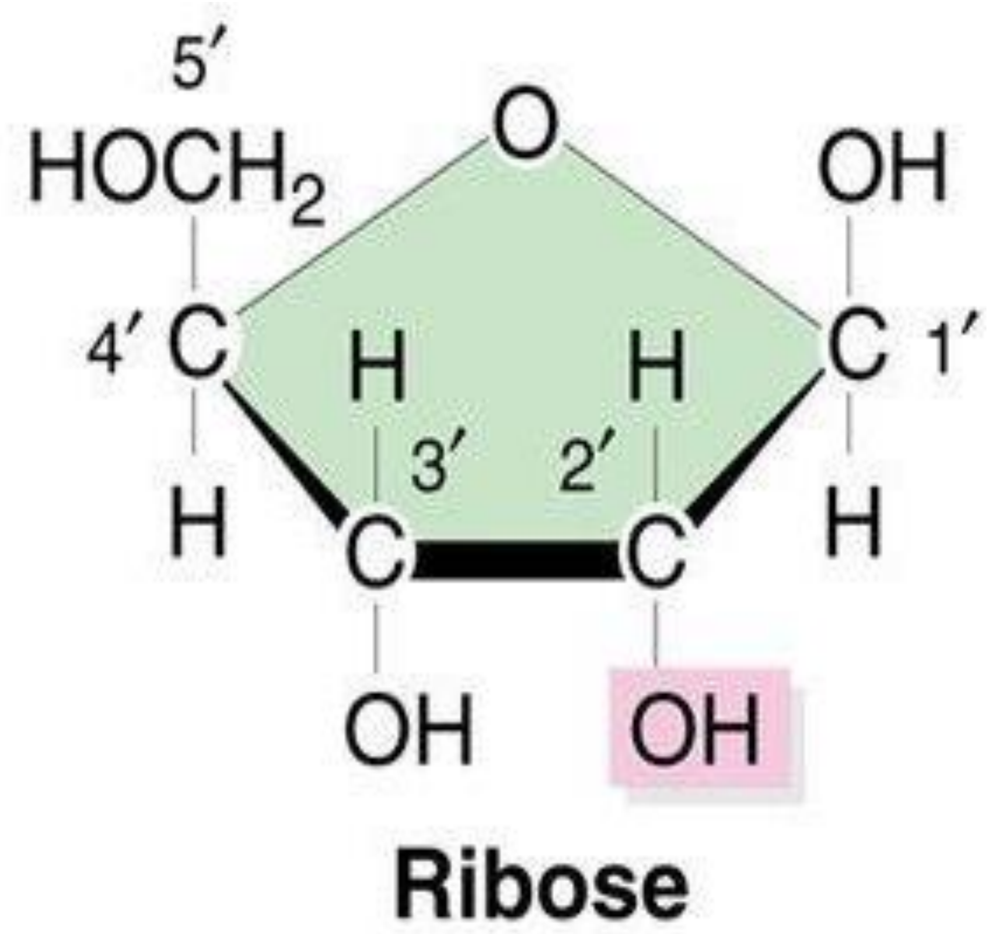
# STRUCTURE OF NUCLEIC ACIDS



# COMPONENT 1: SUGAR



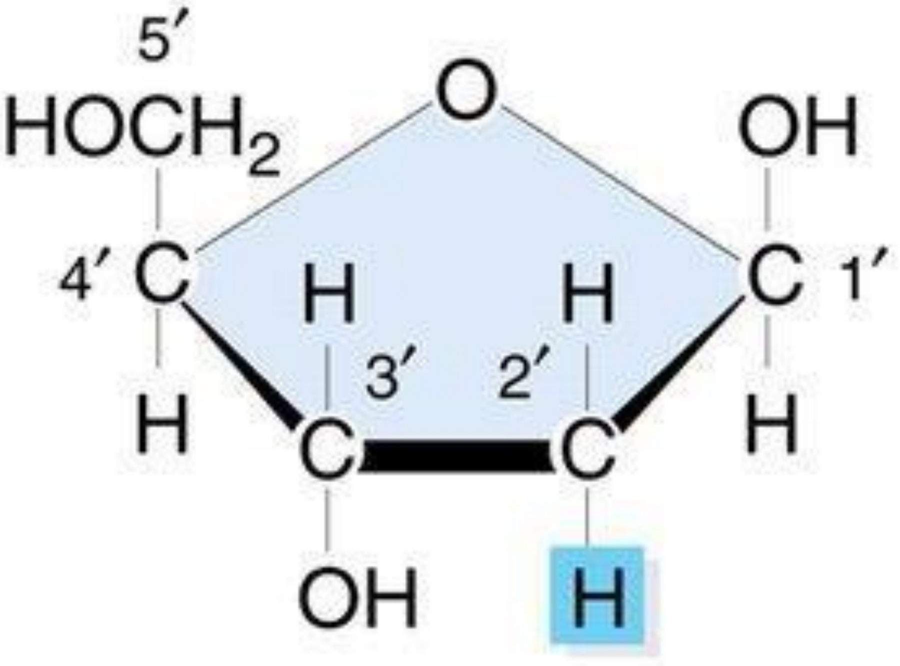

Deoxyribose Sugar Present in DNA




Ribose Sugar Present in RNA

# Importance of Carbon Numbering in Pentose sugar

The carbon atoms of pentose sugar are numbered **1′ to 5′**, and each carbon has a specific function.



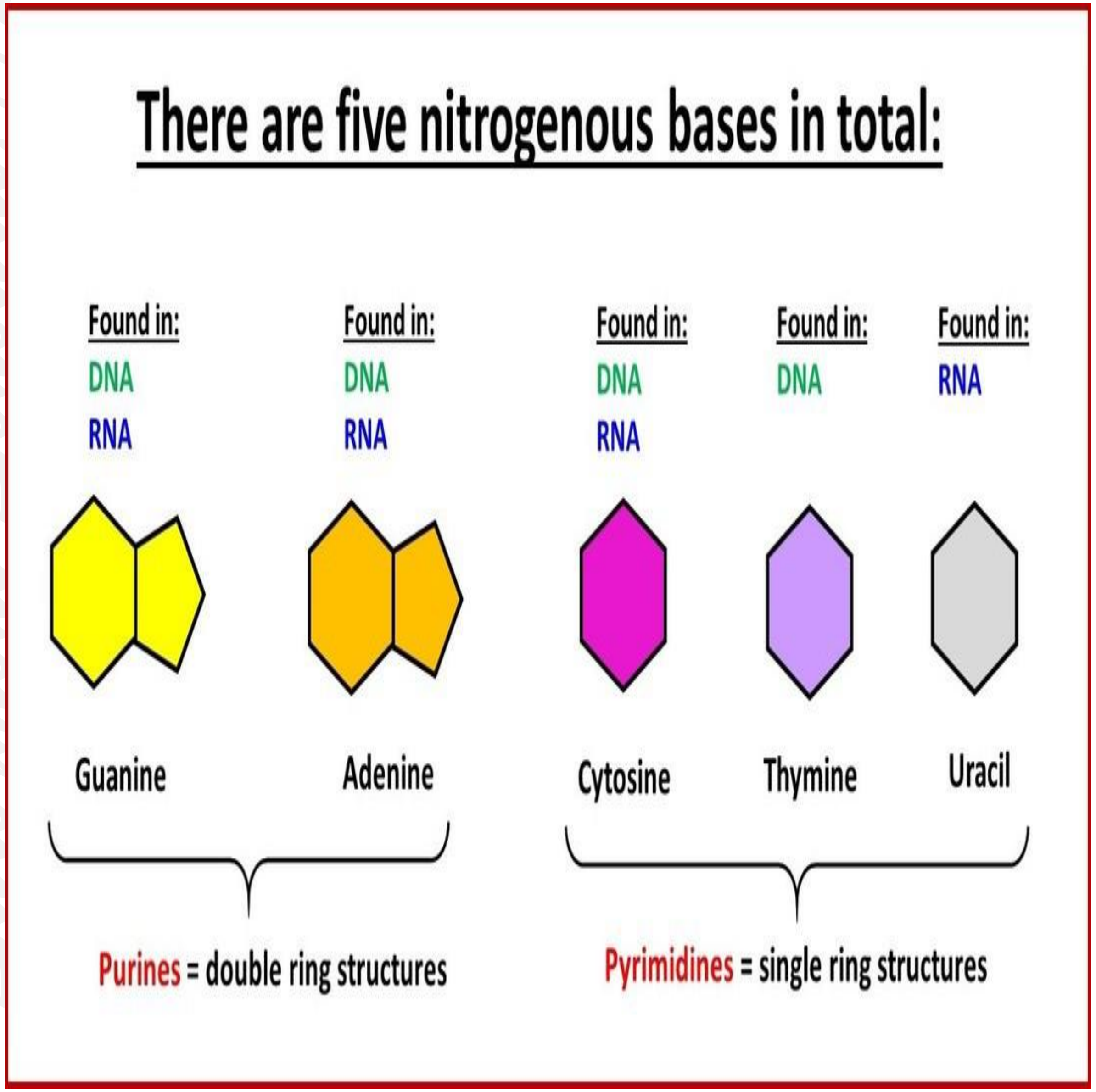

**Deoxyribose**

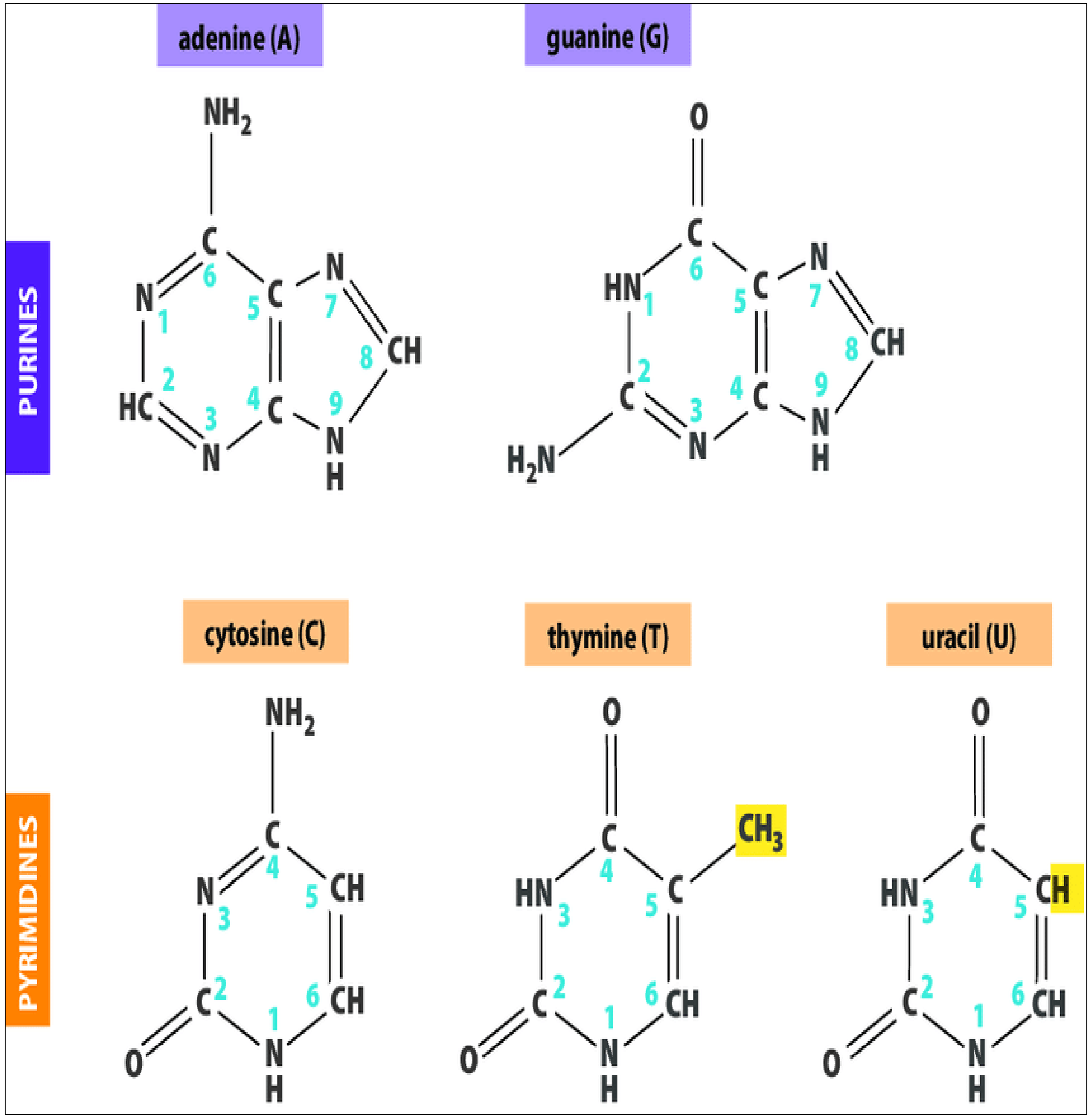
| CARBON ATOM | FUNCTION |
|---|---|
| 1′ Carbon | Attaches the **nitrogenous base** through an N-glycosidic bond. |
| 2′ Carbon | Determines whether the sugar is **deoxyribose (–H)** or **ribose (–OH).** |
| 3′ Carbon | Contains a hydroxyl (–OH) group that forms the **3′–5′ phosphodiester bond** with the next nucleotide. |
| 4′ Carbon | Forms part of the sugar ring and connects to the 5′ carbon. |
| 5′ Carbon | Attaches the **phosphate group**, which links nucleotides together to form the sugar-phosphate backbone. |

# Difference Between Deoxyribose and Ribose

| Features | Deoxyribose (DNA) | Ribose (RNA) |
|---|---|---|
| Chemical formula | $C_5H_{10}O_4$ | $C_5H_{10}O_5$ |
| 2′ Carbon | –H | –OH |
| Stability | More stable | Less stable |
| Reactivity | Less reactive | More reactive |
| Found in | DNA | RNA |
| Function (DNA & RNA) | Long-term genetic information storage | Protein synthesis and gene expression |

# COMPONENT 2: NITROGENOUS BASES



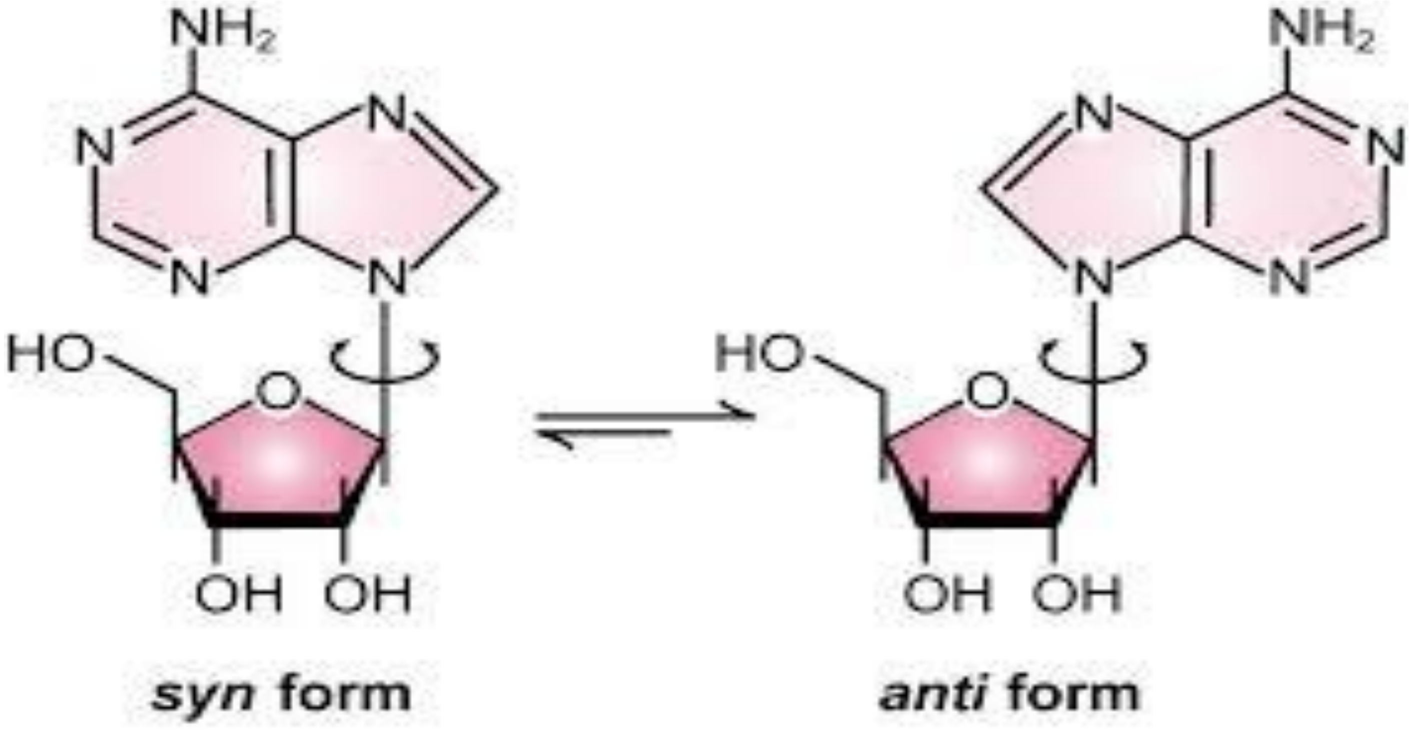



**Syn conformation:**

- The base is **rotated towards the same side of the sugar molecule** as the phosphate group.

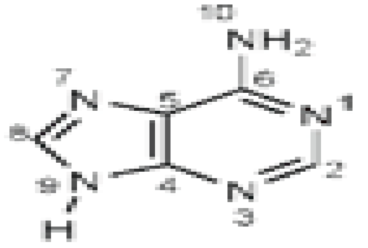
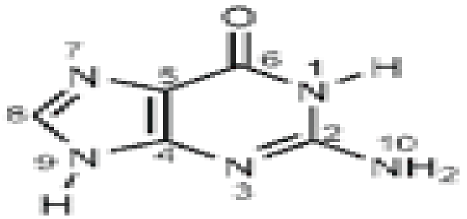
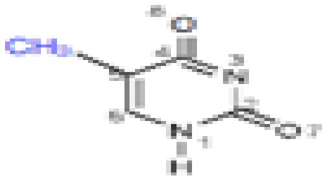
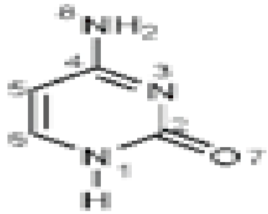
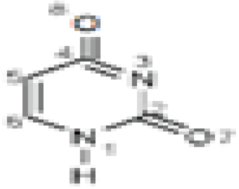
**Anti conformation:**

- The base is **rotated away from the sugar molecule on the opposite side of the phosphate group.**



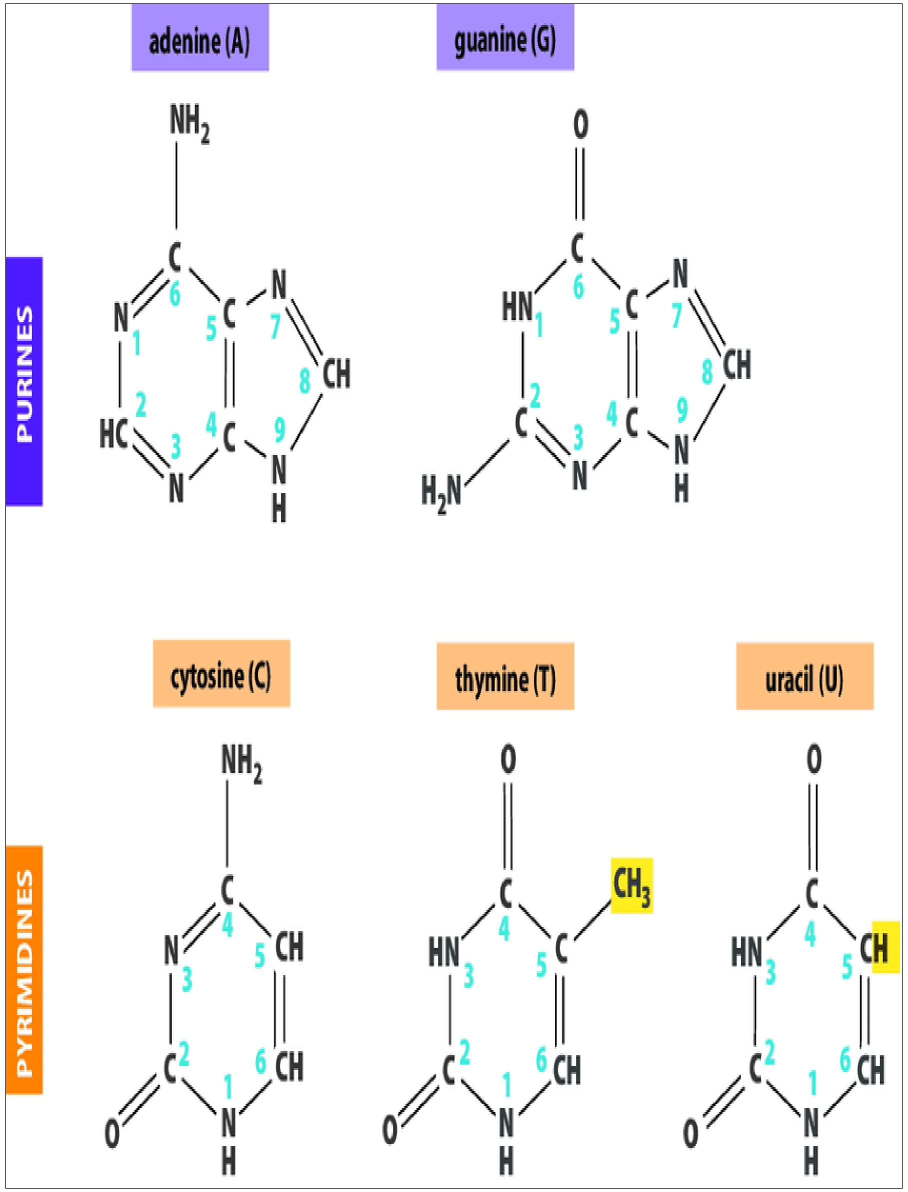

## N-glycosidic bond

This bond connects the nitrogenous base to the sugar molecule (ribose sugar present in RNA, deoxyribose sugar present in DNA).

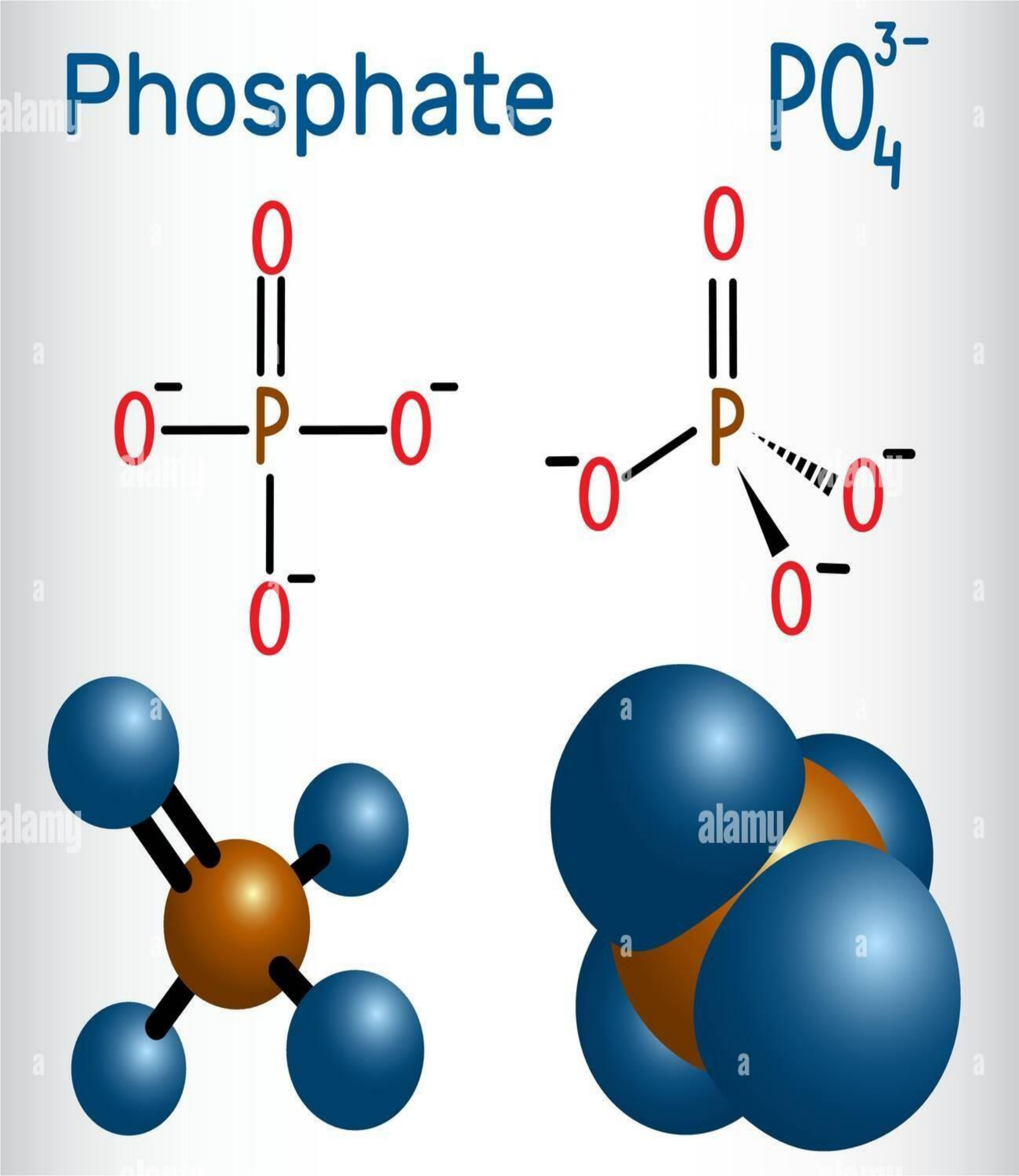
| Nitrogen bases | | IUPAC name | Structure |
|---|---|---|---|
| Purine | Adenine | 6-amino purine |  |
| | Guanine | 2-amino, 6- oxy purines |  |
| Pyrimidine | Thymine | 2, 4- dioxy, 5 methyl pyrimidine |  |
| | Cytosine | 4-amino 2-oxy pyrimidine |  |
| | Uracil | 2, 4- dioxy pyrimidine |  |

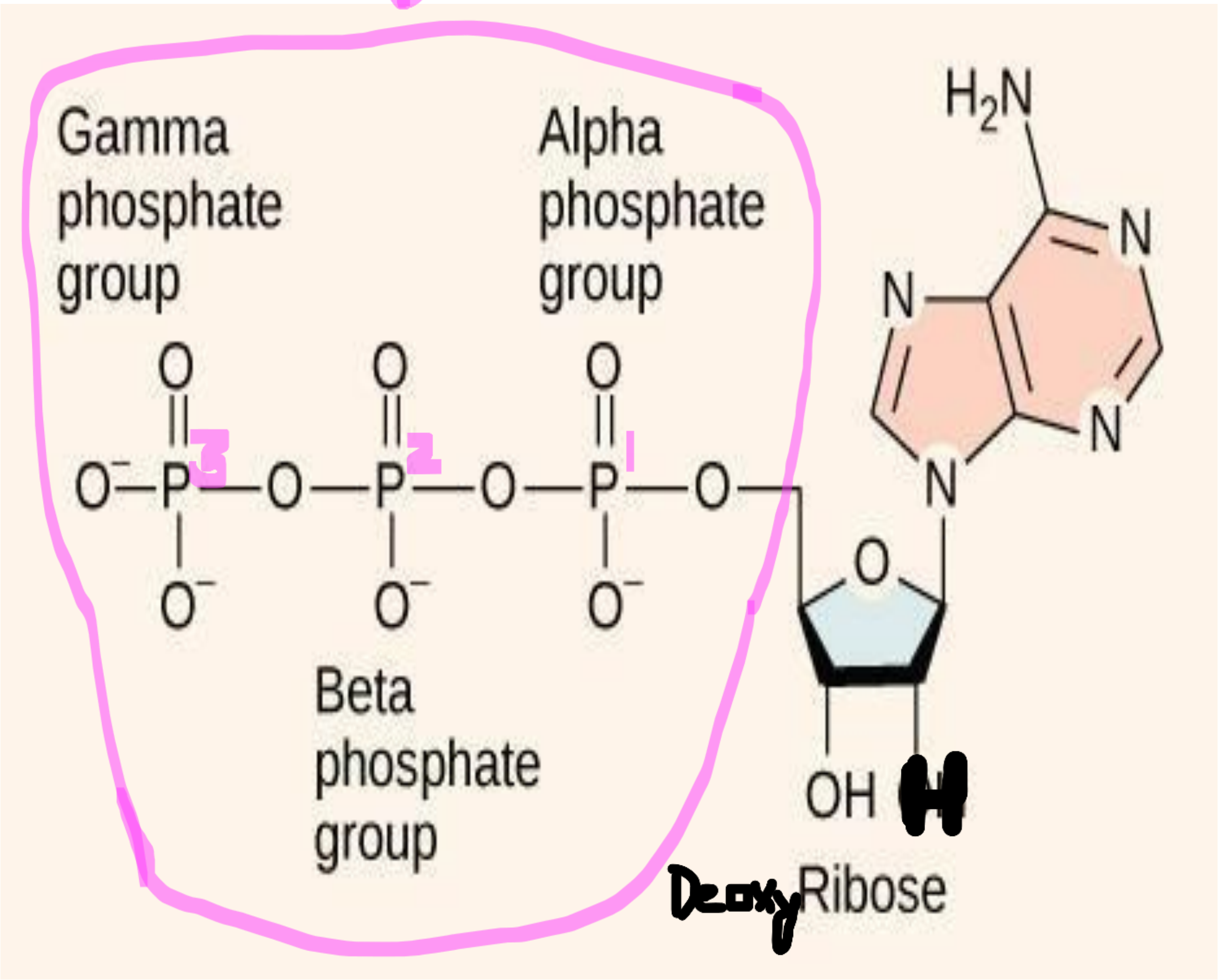
# Difference Between Purines and Pyrimidines

| Feature | Purines | Pyrimidines |
|---|---|---|
| Ring structure | Double-ring (6-membered + 5-membered) | Single six-membered ring |
| Size | Larger | Smaller |
| Number of ring atoms | 9 | 6 |
| Nitrogen atoms | 4<br>Nitrogen atoms are present at **N1, N3, N7 and N9**. | 2<br>Nitrogen atoms are present at **N1 and N3**. |
| Carbon atoms | 5 | 4 |
| Numbering | 1–9 (Anticlockwise) | 1–6 (clockwise) |
| Sugar attachment | N9 atom<br>The **N9 atom** attaches to the **1′ carbon of the pentose sugar** through an **N-glycosidic bond**. | N1 atom<br>The **N1 atom** attaches to the **1′ carbon of the pentose sugar** through an **N-glycosidic bond**. |
| Examples | Adenine (A), Guanine (G) | Cytosine (C), Thymine (T), Uracil (U) |
| Found in DNA | A, G | C, T |
| Found in RNA | A, G | C, U |

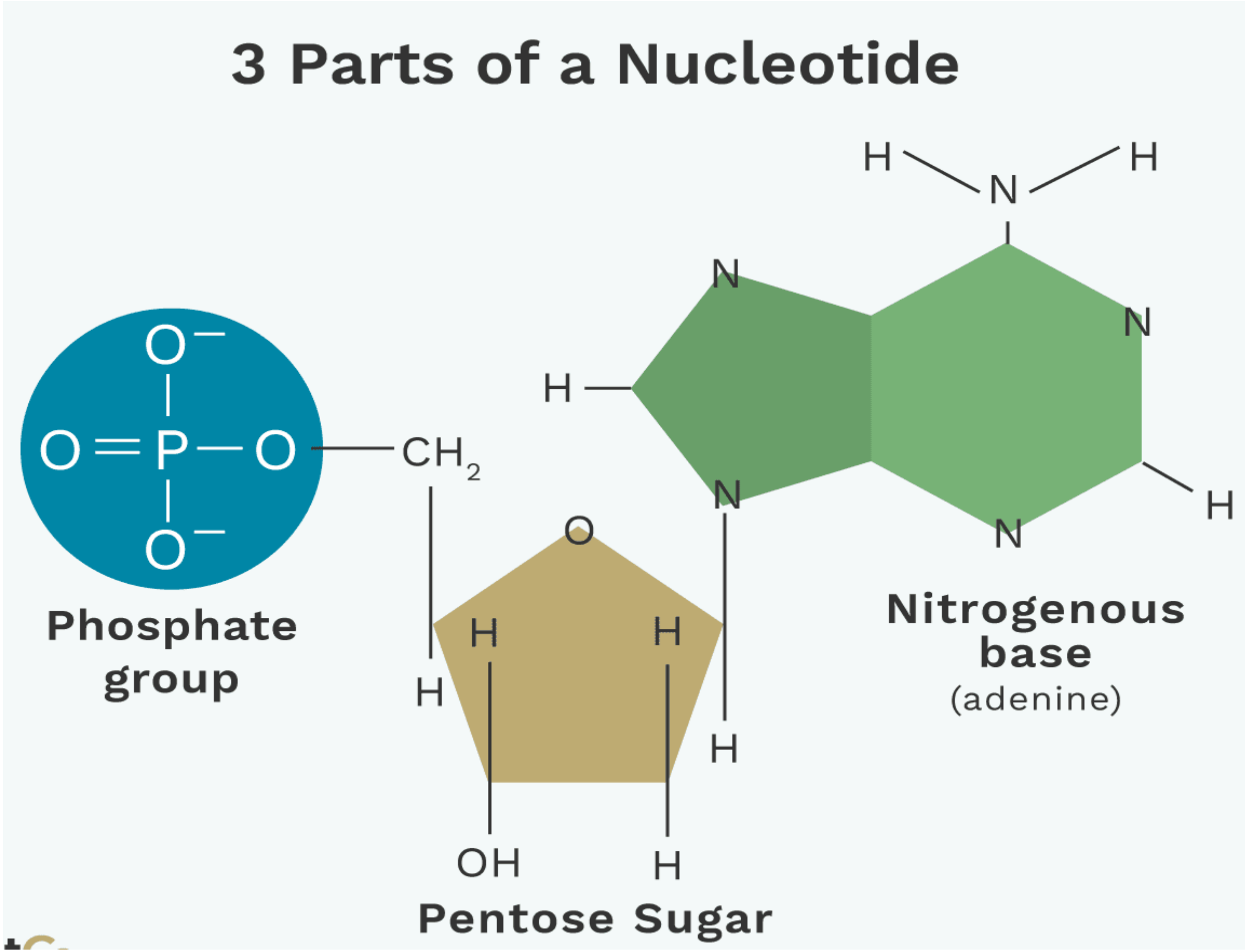


# COMPONENT 3:
# PHOSPHATE GROUP



# 3 Parts OR Components Combine to a Nucleotide



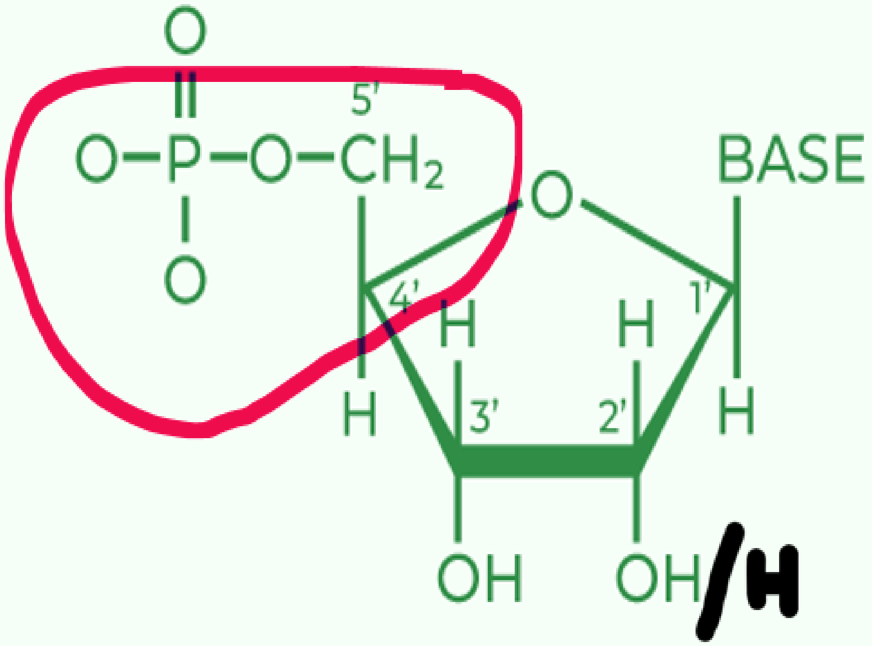

## Structure of a *Nucleotide*

### NUCLEOTIDE

A nucleotide is an organic molecule consisting of a nitrogenous base, pentose sugar, and one or more phosphate groups.

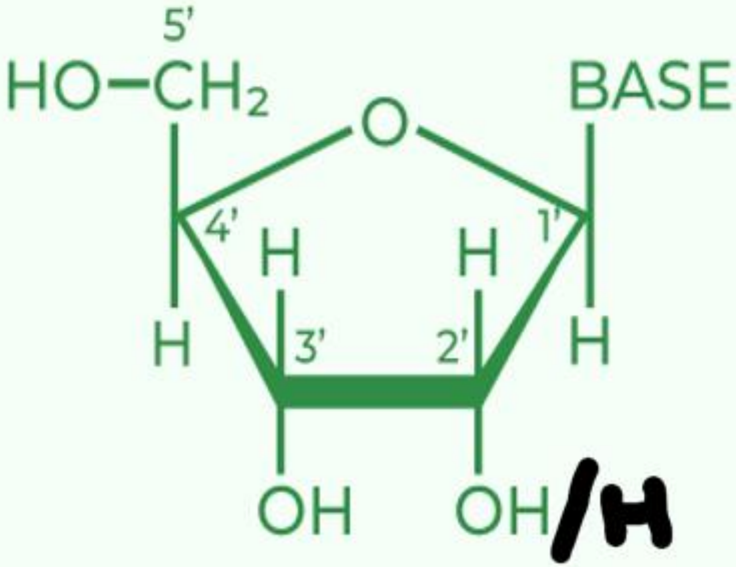
# NUCLEOSIDE AND NUCLEOTIDE

# Difference between
# Nucleotide & Nucleoside




Nucleotide

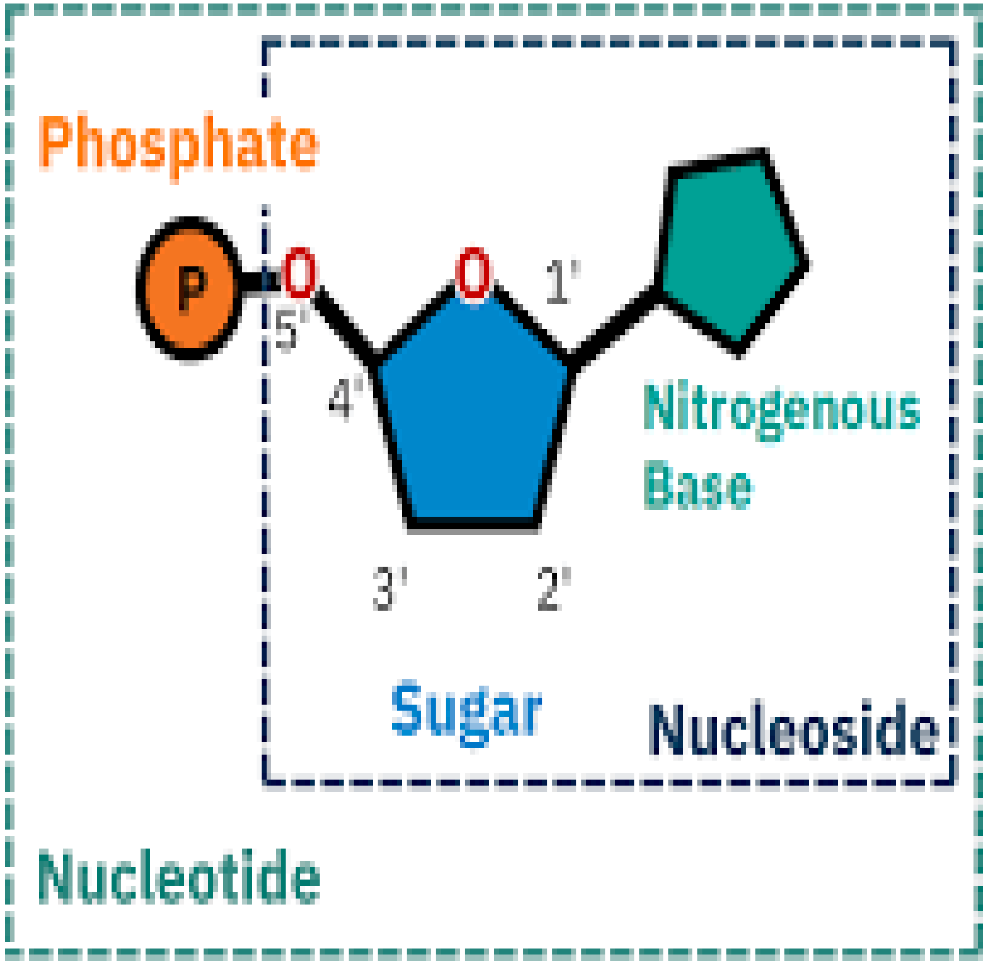
Nitrogenous Base + Pentose Sugar+ Phosphate group




Nucleoside

Nitrogenous Base+ Pentose Sugar
NO Phosphate group will be present

# NUCLEOSIDE AND NUCLEOTIDE




**RNA contains Ribose while DNA contains 2'deoxy-D-Ribose**

**Nucleoside**: Nitrogenous base + ribose:

**Nucleotide and Nucleic Acid Nomenclature**

| Base | Nucleoside* | Nucleotide* | Nucleic acid |
|---|---|---|---|
| **Purines** | | | |
| Adenine | Adenosine | Adenylate | RNA |
| | Deoxyadenosine | Deoxyadenylate | DNA |
| Guanine | Guanosine | Guanylate | RNA |
| | Deoxyguanosine | Deoxyguanylate | DNA |
| **Pyrimidines** | | | |
| Cytosine | Cytidine | Cytidylate | RNA |
| | Deoxycytidine | Deoxycytidylate | DNA |
| Thymine | Thymidine or deoxythymidine | Thymidylate or deoxythymidylate | DNA |
| Uracil | Uridine | Uridylate | RNA |

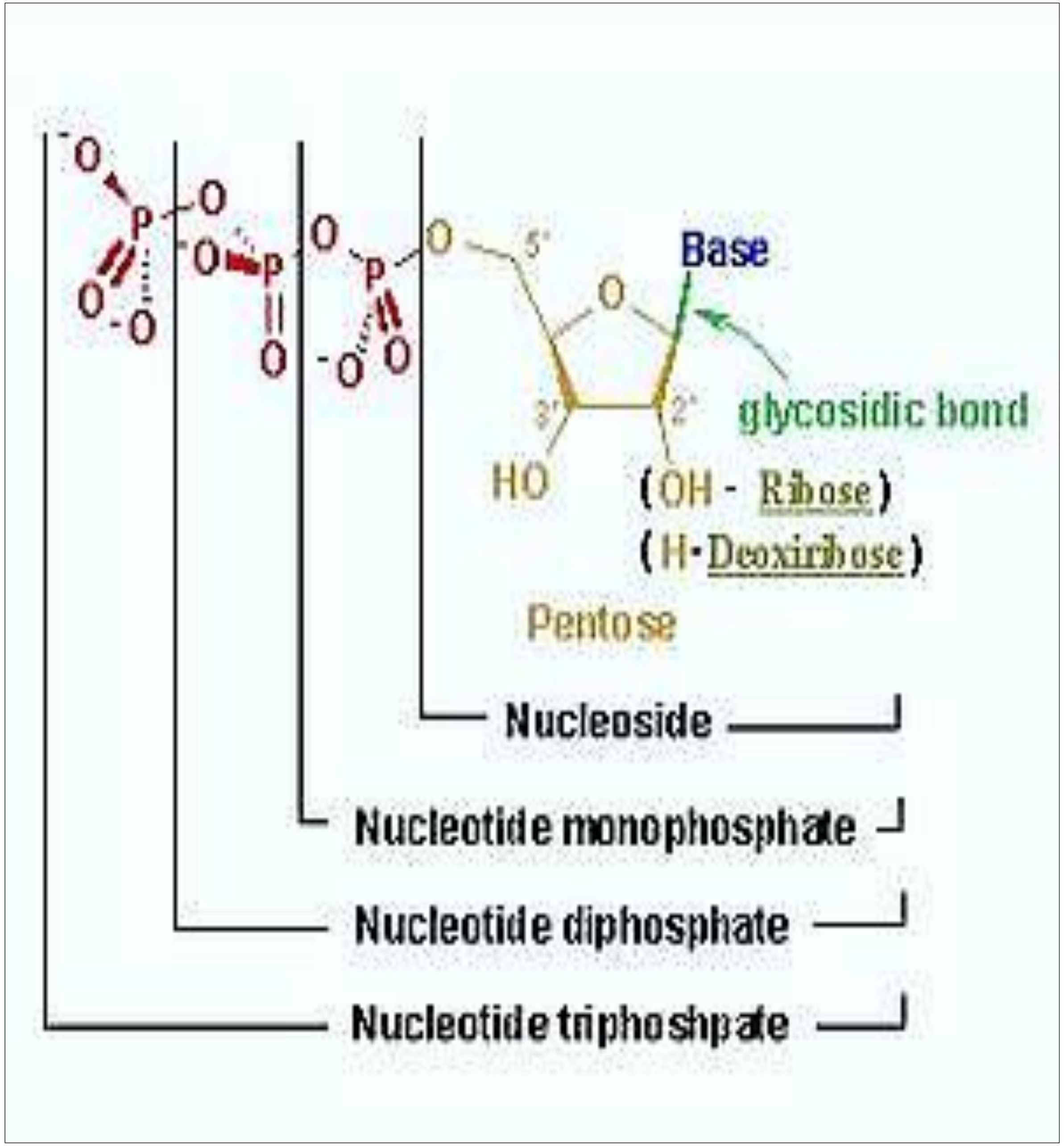
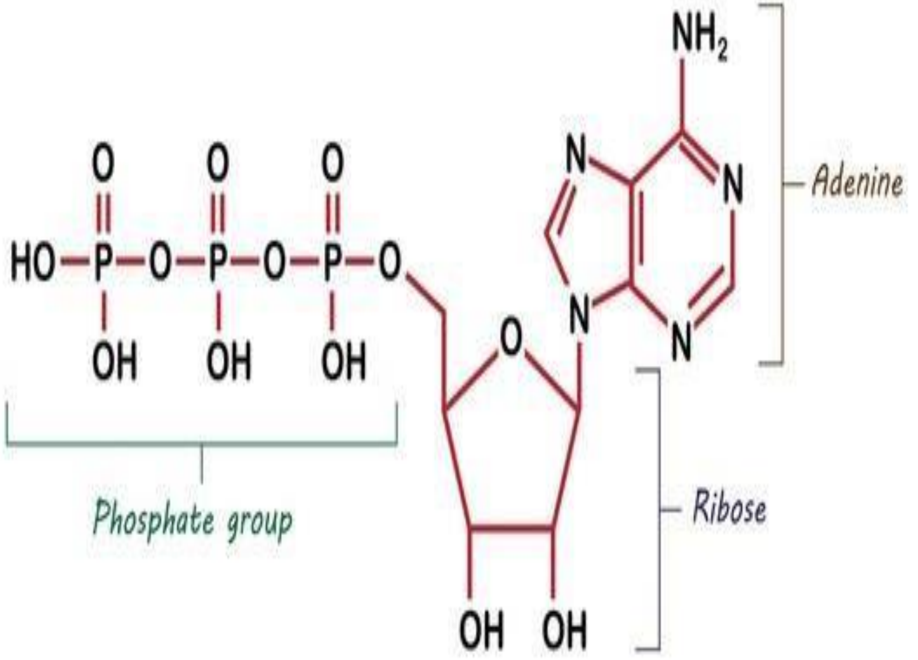



**Table Bases, their nucleosides and nucleotides**

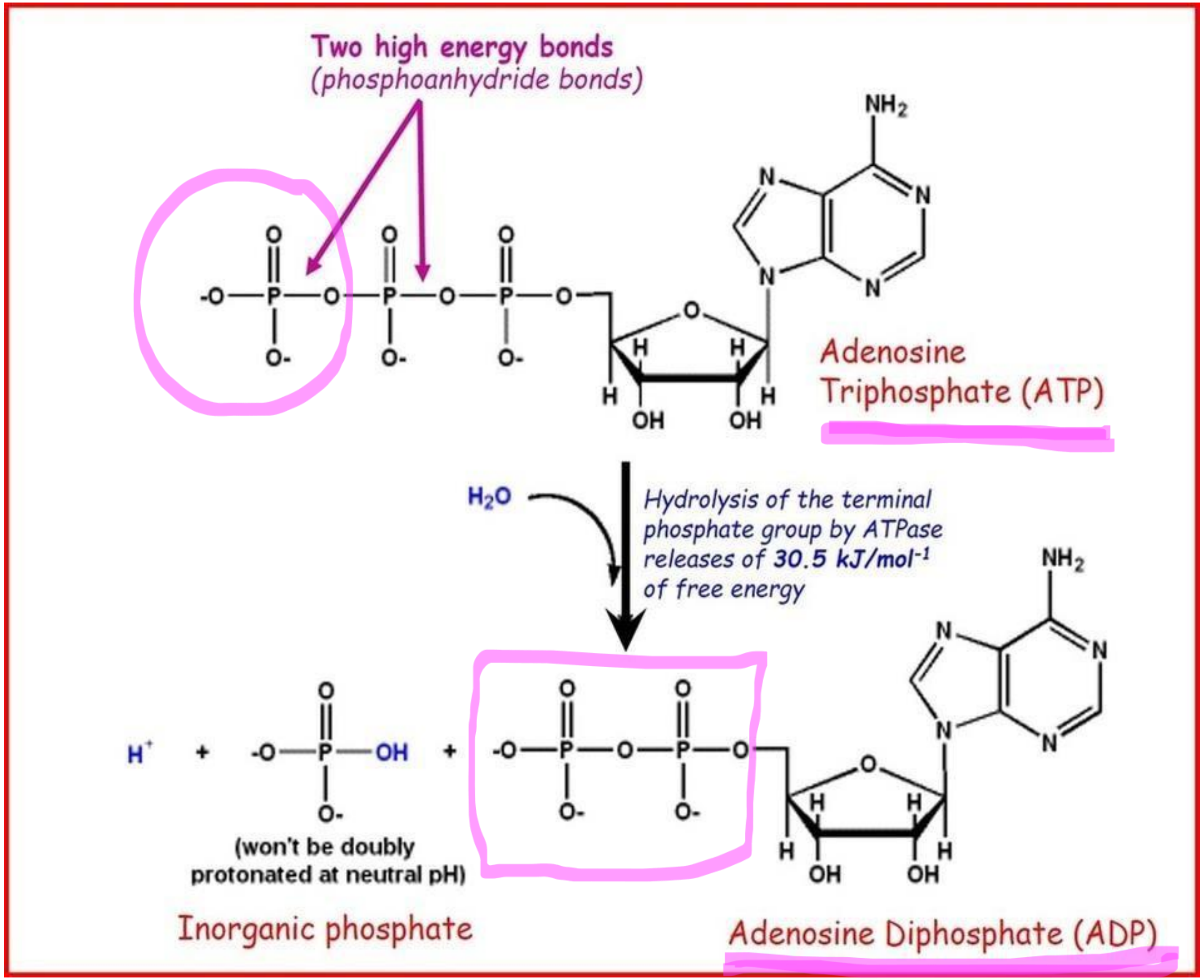
| Name of the base | Sugar | Nucleoside | No. of Phosphate Groups | Nucleotide |
|---|---|---|---|---|
| Adenine | Ribose | Adenosine | 1 | AMP |
| | | | 2 | ADP |
| | | | 3 | ATP |
| | Deoxyribose | Deoxy Adenos-ine | 1 | dAMP |
| | | | 2 | dADP |
| | | | 3 | dATP |
| Guanine | Ribose | Guanosine | 1 | GMP |
| | | | 2 | GDP |
| | | | 3 | GTP |
| | Deoxyribose | Deoxy Guano-sine | 1 | dGMP |
| | | | 2 | dGDP |
| | | | 3 | dGTP |
| Cytosine | Ribose | Cytidine | 1 | CMP |
| | | | 2 | CDP |
| | | | 3 | CTP |
| | Deoxyribose | Deoxy Cytidine | 1 | dCMP |
| | | | 2 | dCDP |
| | | | 3 | dCTP |
| Uracil | Ribose | Uridine | 1 | UMP |
| | | | 2 | UDP |
| | | | 3 | UTP |
| | Deoxyribose | Deoxy Uridine | 1 | dUMP |
| | | | 2 | dUDP |
| | | | 3 | dUTP |
| Thymine | Ribose | Thymidine | 1 | TMP |
| | | | 2 | TDP |
| | | | 3 | TTP |
| | Deoxyribose | Deoxy Thymi-dine | 1 | dTMP |
| | | | 2 | dTDP |
| | | | 3 | dTTP |

# EXAMPLE OF A NUCLEOTIDE

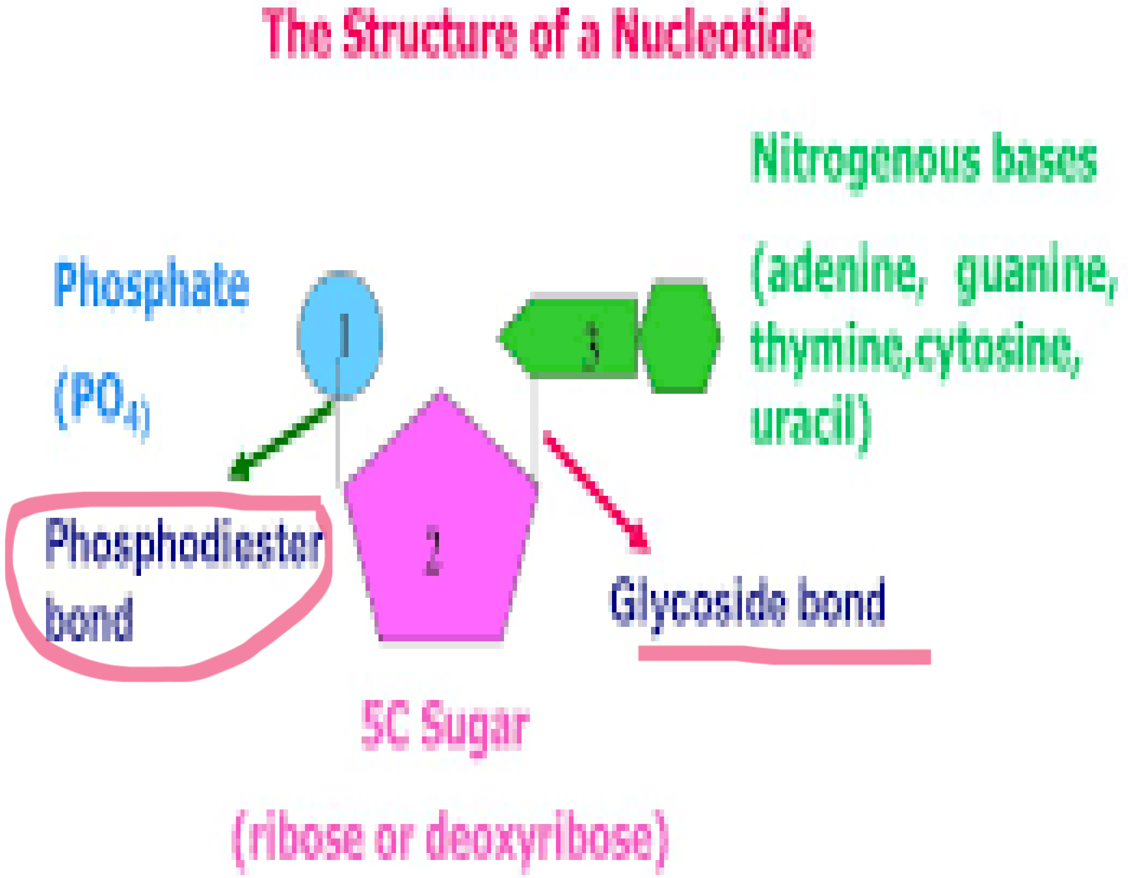
## Adenosine Triphosphate (ATP)



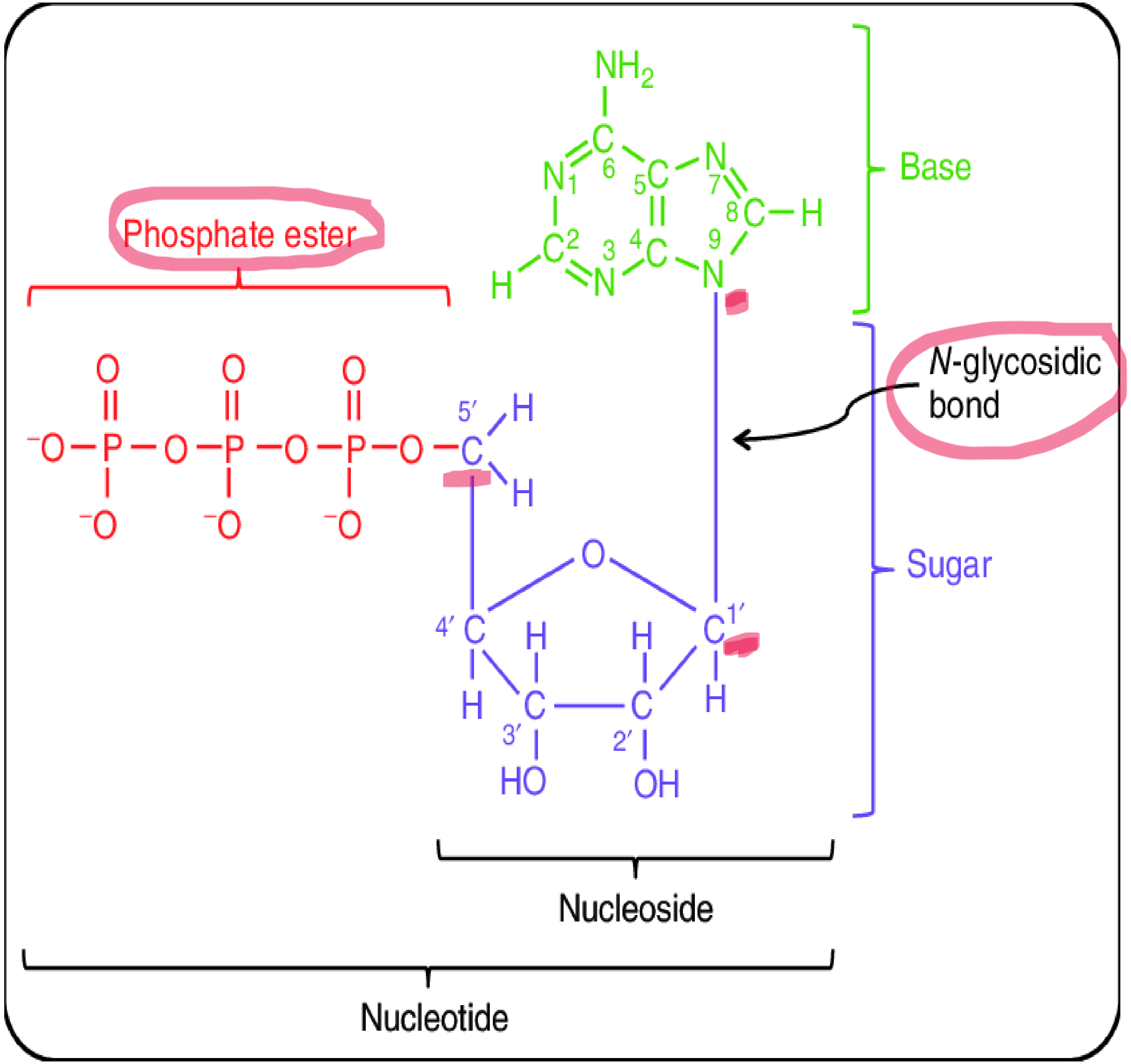

- Energy-carrier in all of living things
- Consist of nitrogenous base (adenine), sugar (ribose) and phosphate group



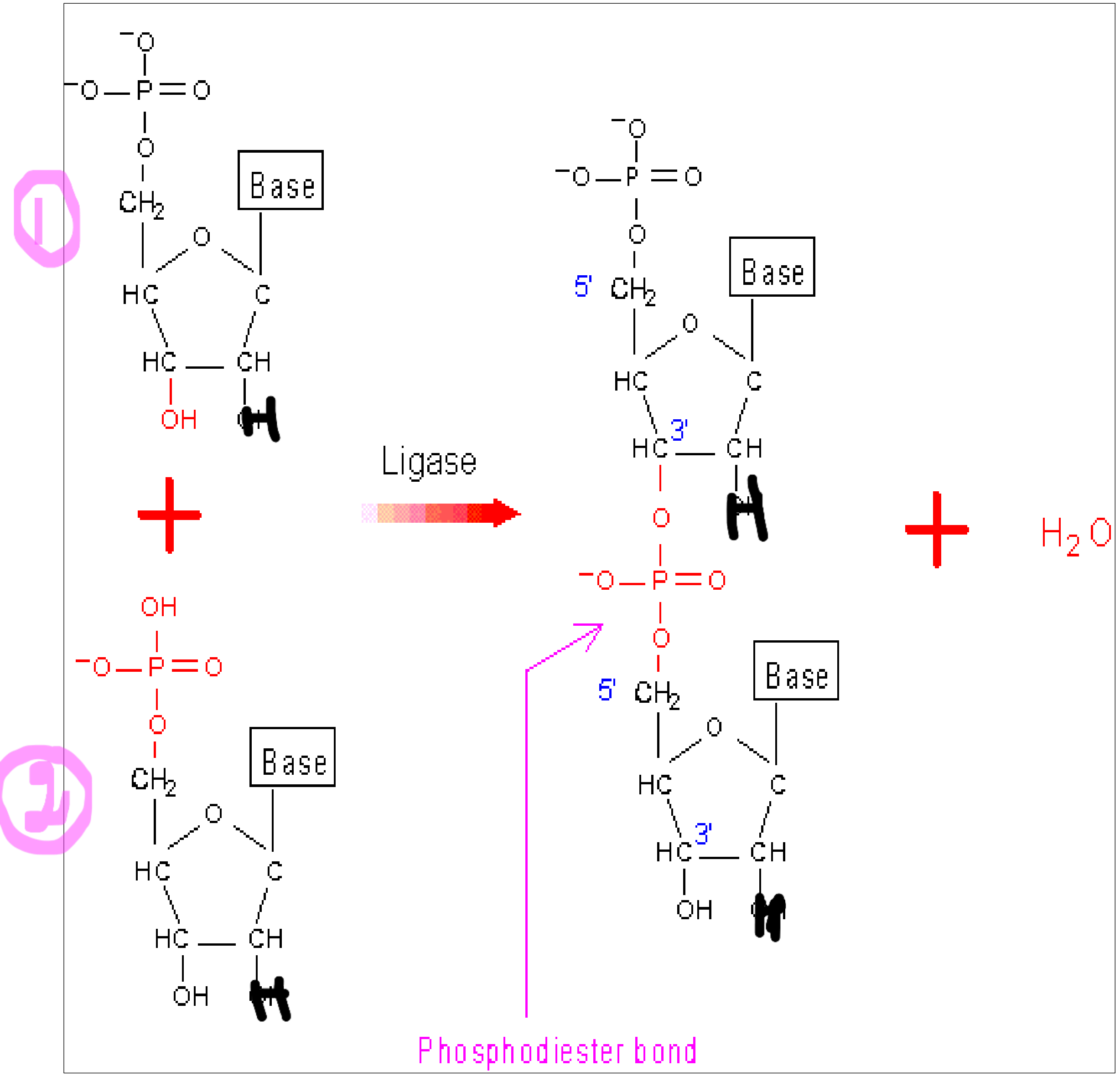
# Linkages or Bonds present in a Nucleotide

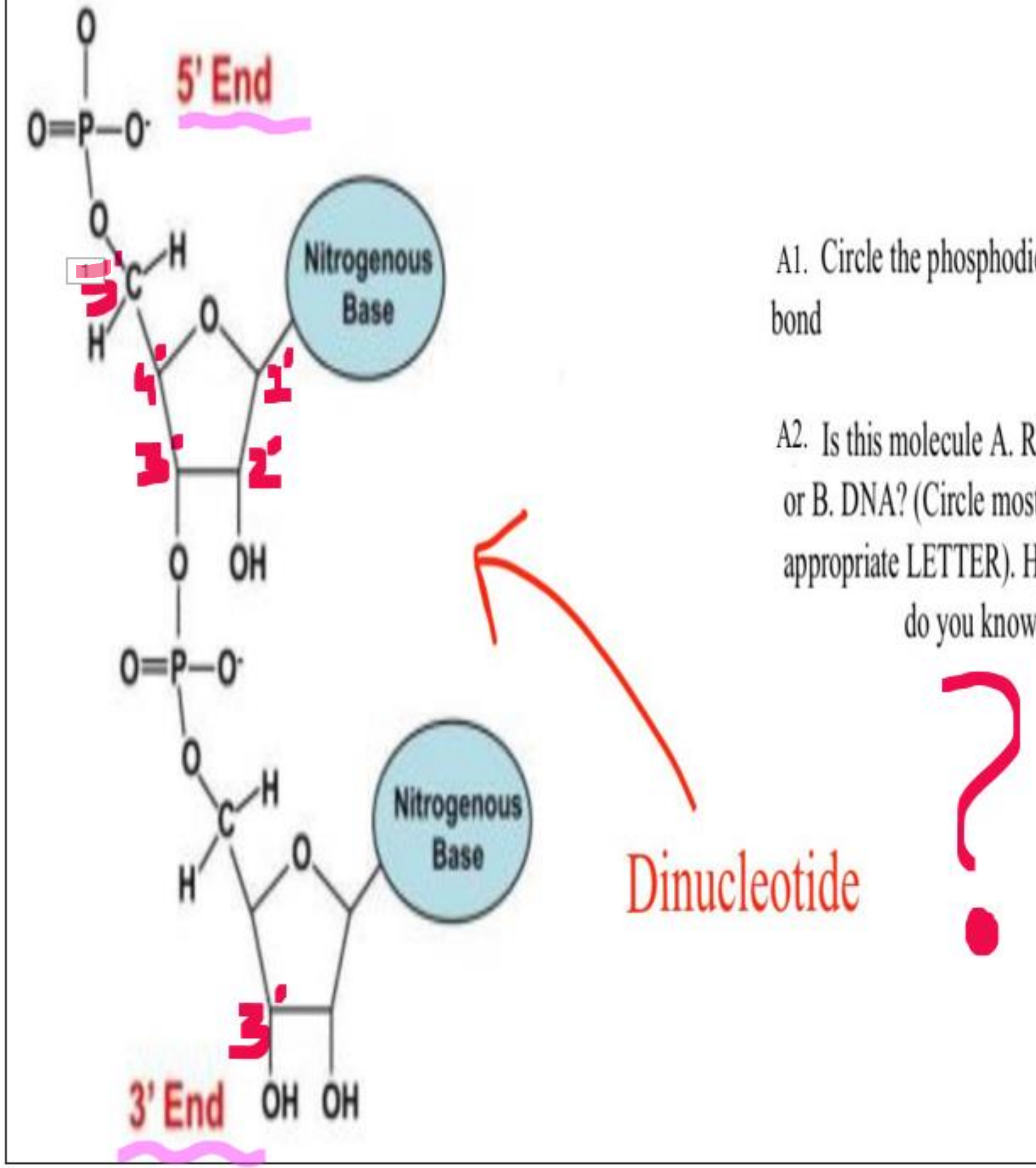



Nucleic acids are polymers of nucleotides.



# Dinucleotide

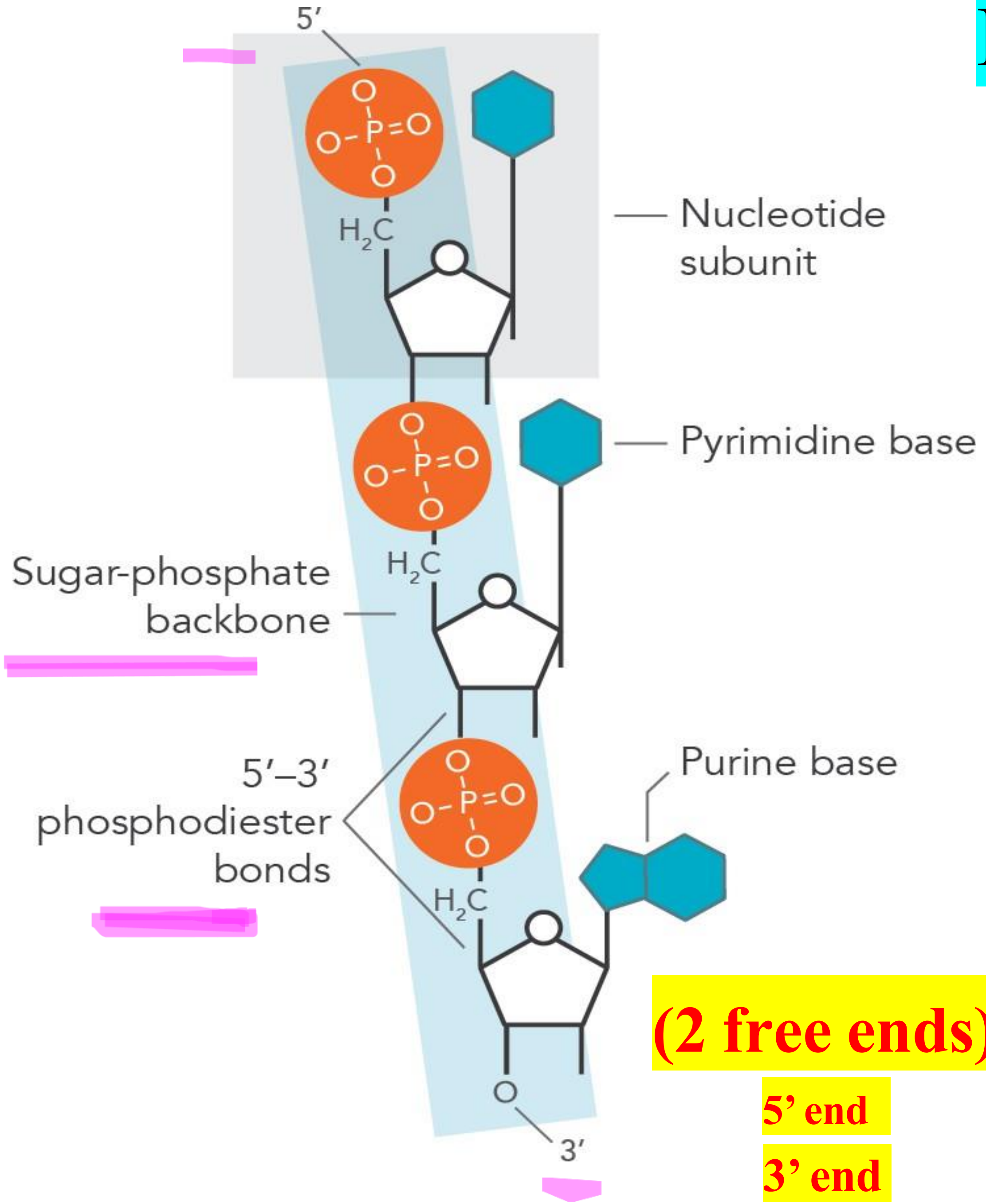



A1. Circle the phosphodiester bond

A2. Is this molecule A. RNA or B. DNA? (Circle most appropriate LETTER). How do you know?

# POLYNUCLEOTIDE CHAIN FORMATION




**(2 free ends)**

**5’ end**

**3’ end**

Individual nucleotides are joined together to form a **polynucleotide chain.**
The bond formed is called the **3′–5′ phosphodiester bond.**

## Steps:

- The **3′ hydroxyl (–OH)** group of one nucleotide reacts with the **5′ phosphate** group of the next nucleotide.
- A molecule of water is removed (condensation reaction).
- A **phosphodiester bond** is formed.

**Sugar-Phosphate Backbone**

Repeated phosphodiester bonds produce a strong backbone.

```
      Base        Base       Base
       |            |          |
Sugar—P—Sugar—P—Sugar—P—Sugar
```

- Backbone forms the **outer framework** of DNA and RNA.
- Nitrogenous bases project inward (DNA) or outward (RNA).

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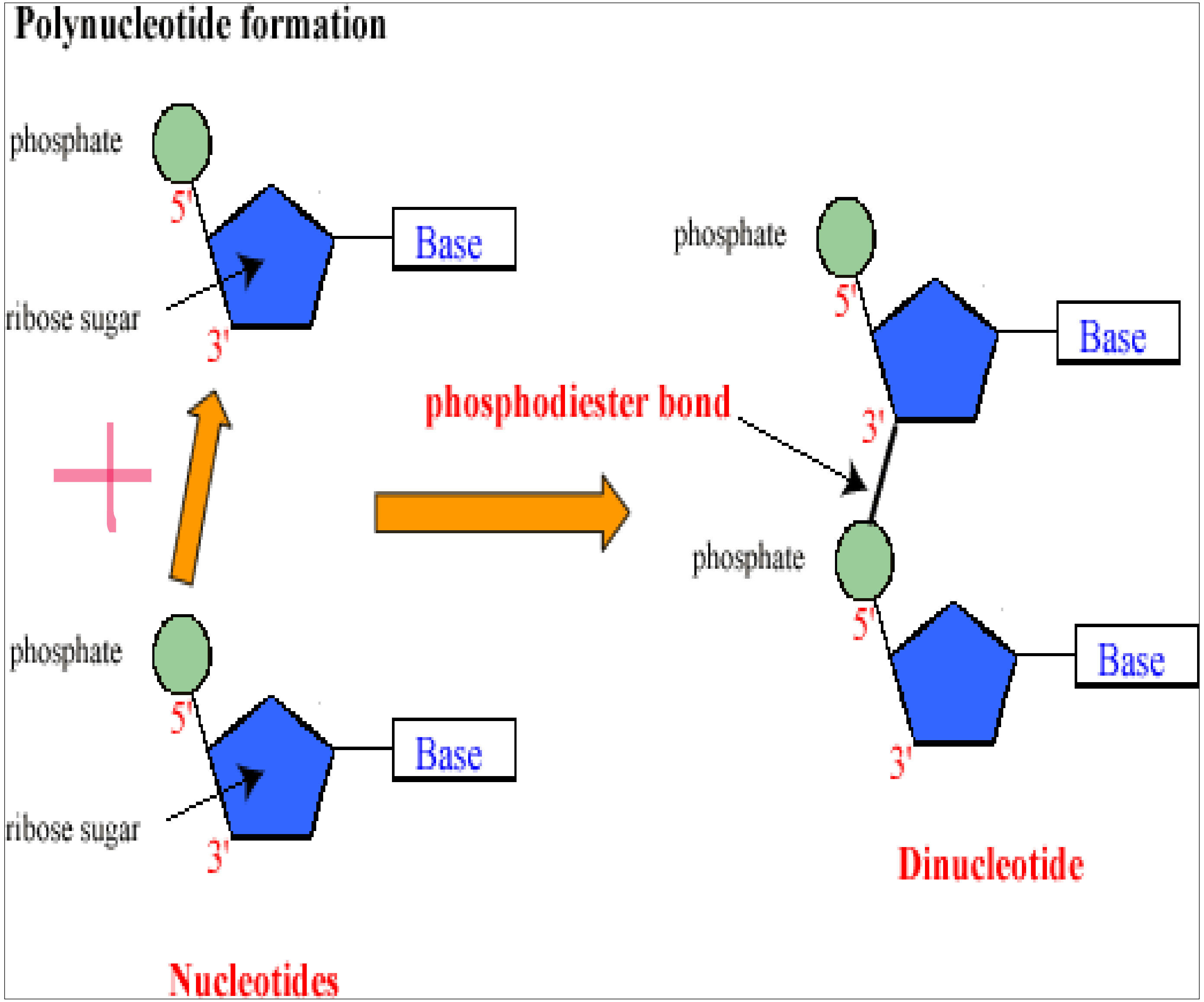
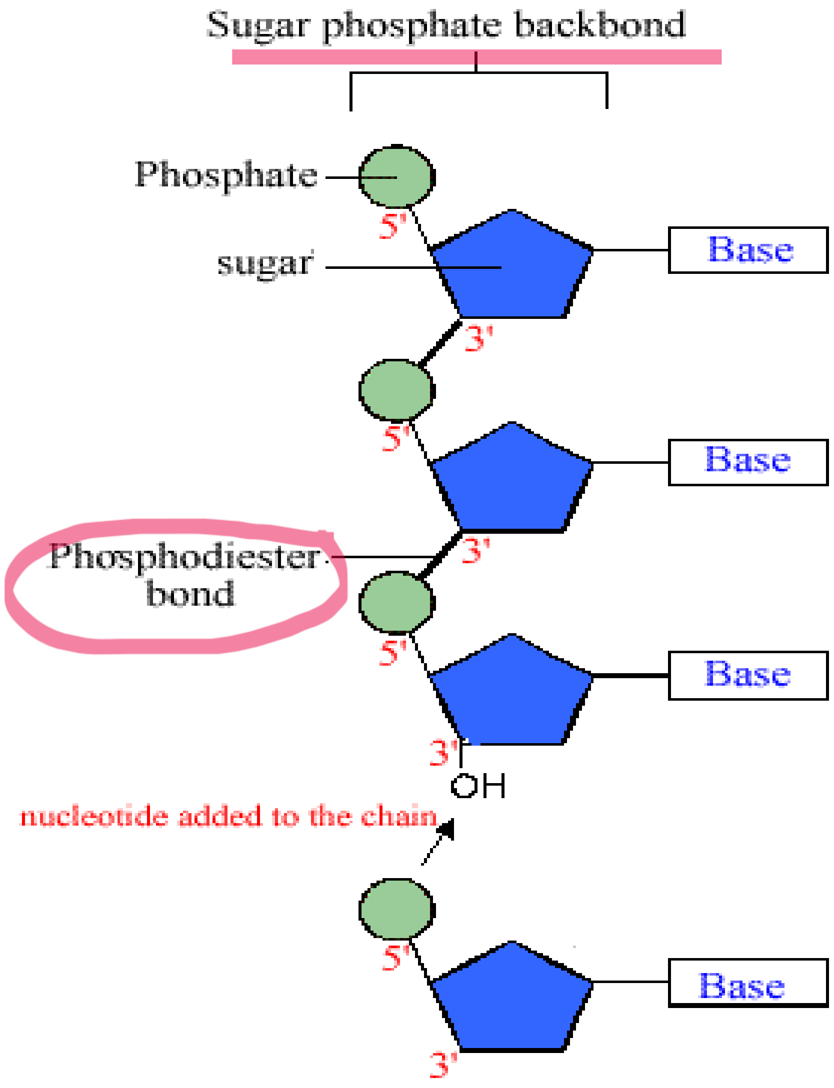
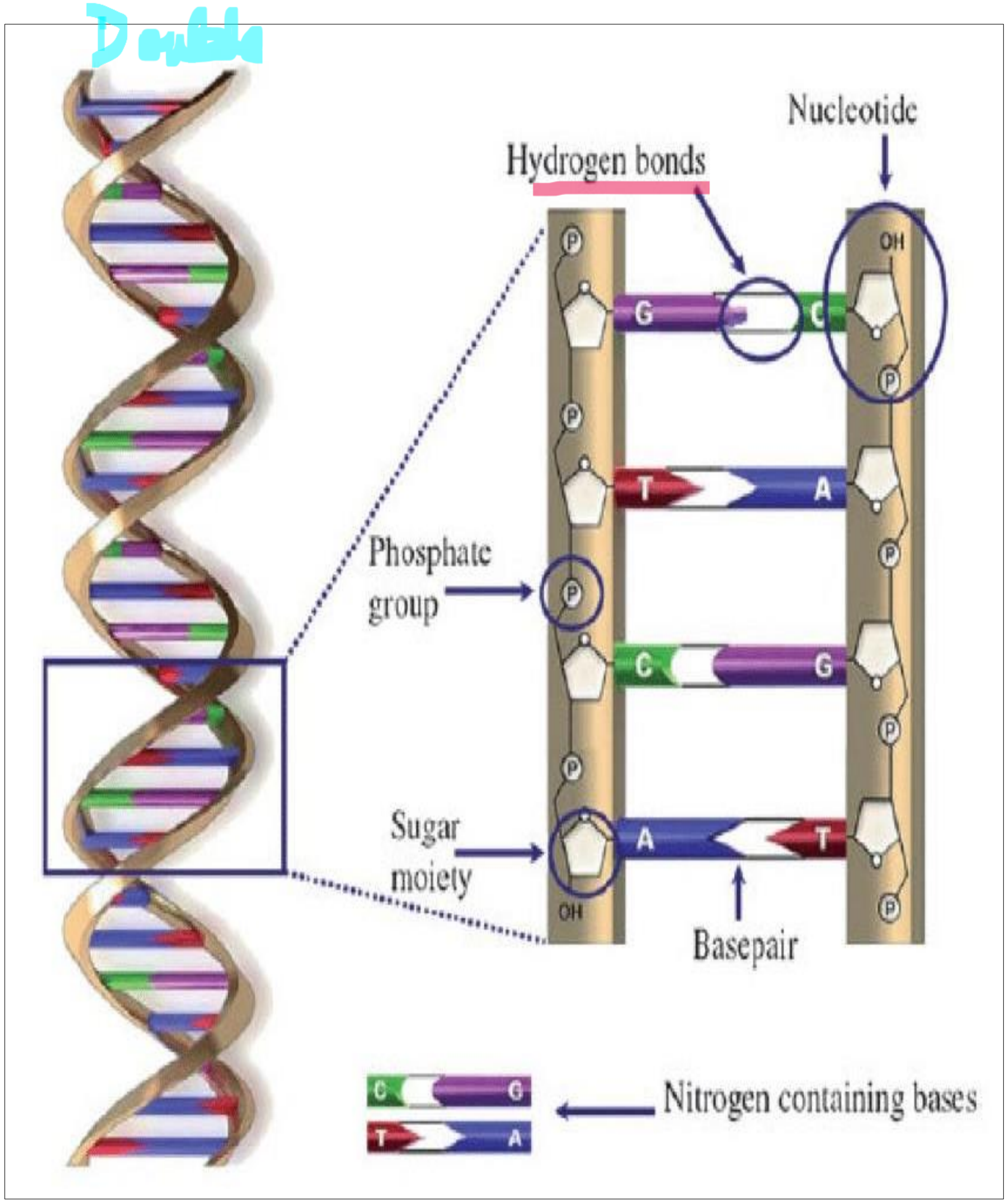
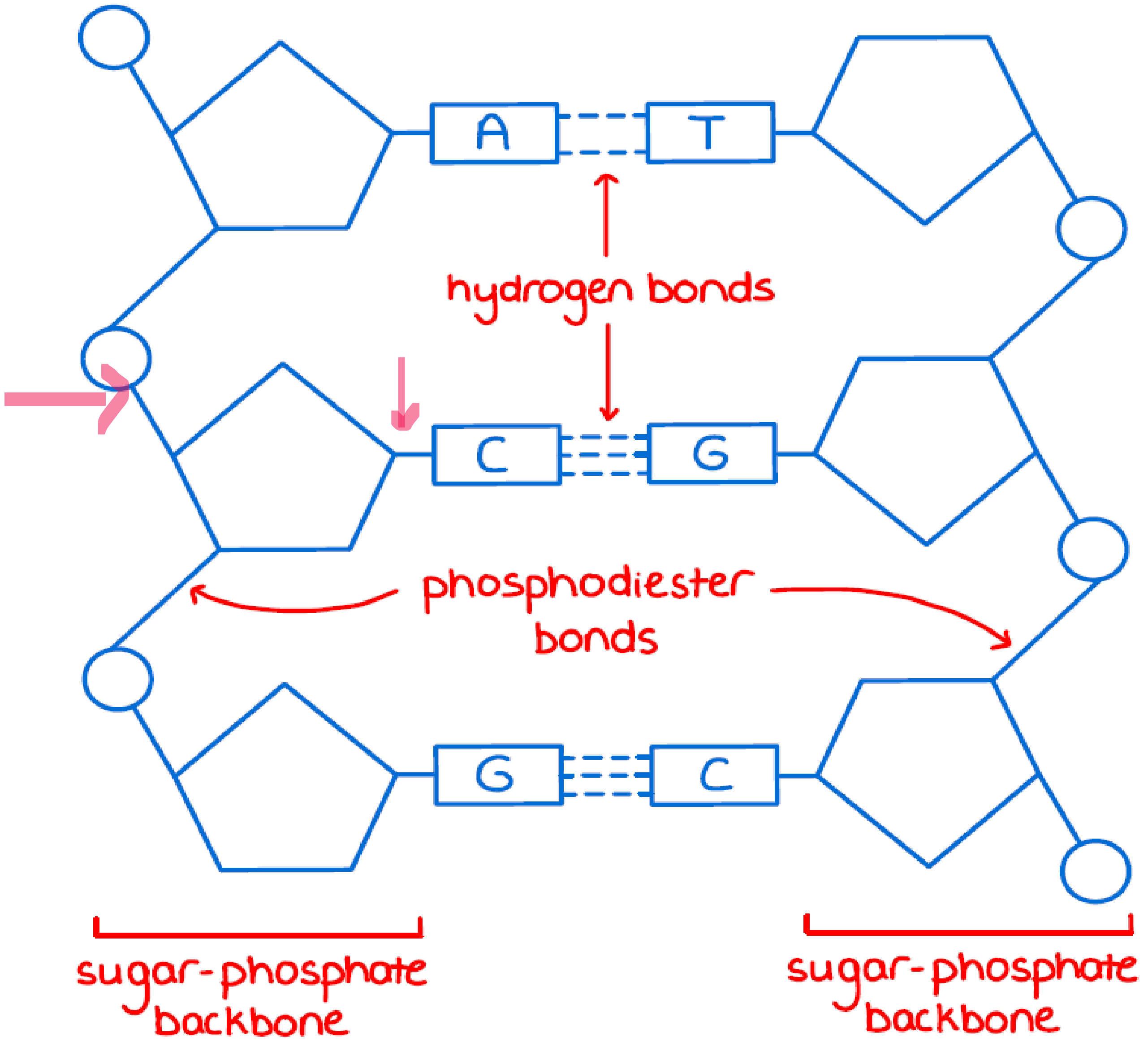
# POLYNUCLEOTIDE CHAIN FORMATION & BOND



# Bonds present in a Nucleic acid (DNA)



# NUCLEIC ACIDS- STRUCTURE

Nucleic acids are polymers or long chain of Nucleotides.
A nucleotide is the **basic structural and functional unit (monomer)** of nucleic acids.
Every nucleotide consists of **three components**:: Nitrogenous Base, Pentose Sugar & Phosphate Group

## 1. Pentose Sugar

Pentose sugar is one of the three components of a nucleotide. It is a **five-carbon (5C) monosaccharide** in which the carbon atoms are numbered **1′ to 5′**. The type of sugar determines whether the nucleic acid is **DNA** or **RNA**.

**Two types of Pentose Sugar present:**

**1. Deoxyribose sugar (DNA)**
**Chemical formula:** $C_5H_{10}O_4$

- Present only in **DNA**
- The **2′ carbon contains a hydrogen atom (–H)** instead of a hydroxyl group.
- Less chemically reactive. More stable than ribose.
- This makes it suitable for the long-term storage of genetic information.

**2. Ribose sugar (RNA)**
**Chemical formula:** $C_5H_{10}O_5$

- Present only in **RNA**
- The **2′ carbon contains a hydroxyl group (–OH)**.
- More chemically reactive. Less stable than DNA.
- Easily hydrolyzed due to the presence of the –OH group.

## 2. Phosphate Group

The phosphate group is derived from **phosphoric acid ($H_3PO_4$)**.

3 active OH groups are present
Involve in strand formation.

**Phosphate group Gives Negative Charge to nucleic acids so,** DNA and RNA are negatively charged because every nucleotide contains a phosphate group.

The sugar-phosphate backbone protects genetic information &
**provides Stability**

Phosphate forms **Joins Nucleotides**
By **3′–5′ phosphodiester bonds**, connecting adjacent nucleotides into long chains.

# NUCLEIC ACIDS- STRUCTURE

## 3. Nitrogenous Base

Nitrogenous bases are **heterocyclic aromatic compounds** containing nitrogen atoms. There are **five nitrogenous bases (A,G C,T and U)**

### These are group into two types

**A. Purines (Double-ring structure)**

Purines are nitrogenous bases that contain **two fused rings** (one six-membered ring and one five-membered ring).
Purines contain **9 atoms in the ring system** (5 carbon atoms and 4 nitrogen atoms). The atoms are numbered from **1 to 9 (anticlockwise)**
They are larger molecules. It includes A & G

**Adenine (A)**

- Present in DNA and RNA
- Pairs with Thymine in DNA and Pairs with Uracil in RNA
- It contain amino group (NH2) at 6 Carbon position of the purine.

**Guanine (G)**

- Present in DNA and RNA and Pairs with Cytosine
- Contains amino group and oxy group at 2 and 6 Carbon position of purine

Nitrogen atoms are present at **N1, N3, N7 and N9.**
The **N9 atom** attaches to the **1′ carbon of the pentose sugar** through an **N-glycosidic bond.**

**B. Pyrimidines (Single-ring structure)**

Pyrimidines are **smaller nitrogenous bases** consisting of **a single six-membered ring.** Pyrimidines contain **6 atoms in the ring** (4 carbon atoms and 2 nitrogen atoms).The atoms are numbered from **1 to 6.**
Nitrogen atoms are present at **N1 and N3.**
The **N1 atom** attaches to the **1′ carbon of the pentose sugar** through an **N-glycosidic bond.** It contains C, T and U

**Cytosine (C)**

- Present in DNA and RNA and Pairs with Guanine. Contains amino and oxy group at 4$^{th}$ and 2$^{nd}$ C of pyrimidine

**Thymine (T)**

- Present only in DNA. Contains a methyl ($-CH_3$) group at C5 of pyrimidine that increases DNA stability along with 2 oxy group at 2$^{nd}$ and 4$^{th}$ C of pyrimidine.

**Uracil (U)**

- Present only in RNA. Replaces thymine
- Lacks the methyl group present in thymine and only contains 2 oxy group at 2$^{nd}$ and 4$^{th}$ C of pyrimidine .

# NUCLEIC ACIDS- STRUCTURE: Formation of a Polynucleotide Chain

Individual nucleotides are joined together to form a **polynucleotide chain**.
The bond formed is called the **3′–5′ phosphodiester bond**.

## Steps:

- The **3′ hydroxyl (–OH)** group of one nucleotide reacts with the **5′ phosphate** group of the next nucleotide.
- A molecule of water is removed (condensation reaction).
- A **phosphodiester bond** is formed.

**Sugar-Phosphate Backbone**

Repeated phosphodiester bonds produce a strong backbone.

```
               Base         Base       Base
                |             |          |
Sugar—P—Sugar—P—Sugar—P—Sugar
```

- Backbone forms the **outer framework** of DNA and RNA.
- Nitrogenous bases project inward (DNA) or outward (RNA).