CHEMICAL NATURE OF GENETIC MATERIAL:

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Molecular Biology

Semester I

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Outline

- Introduction to Genetic Material
- Chemical Composition
- Structure of DNA
- RNA Structure
- Sugar–Phosphate Backbone: provides stability and connects nucleotides.
- Denaturation and Renaturation
- Conclusion

Objectives

By the end of this lecture, students should be able to:

1. Describe the chemical composition of nucleic acids (DNA and RNA).
2. Explain the structure of nucleotides and their components.
3. Differentiate between DNA and RNA.
4. Understand base-pairing rules and the sugar–phosphate backbone.
5. Define and explain denaturation and renaturation of DNA.

Introduction: The Genetic Material

- **The genetic material** is the substance responsible for storing, transmitting, and expressing hereditary information in all living organisms. It determines the traits and functions of an organism and ensures continuity from one generation to the next.
- **Key Concepts**
  - DNA (Deoxyribonucleic Acid): The primary genetic material in all living organisms except certain viruses. It provides the blueprint for coding for proteins and enzymes.
  - RNA (Ribonucleic Acid): Acts as the genetic material in some viruses (e.g., retroviruses like HIV). RNA plays critical roles in gene expression, protein synthesis, and regulation.

Introduction: The Genetic Material

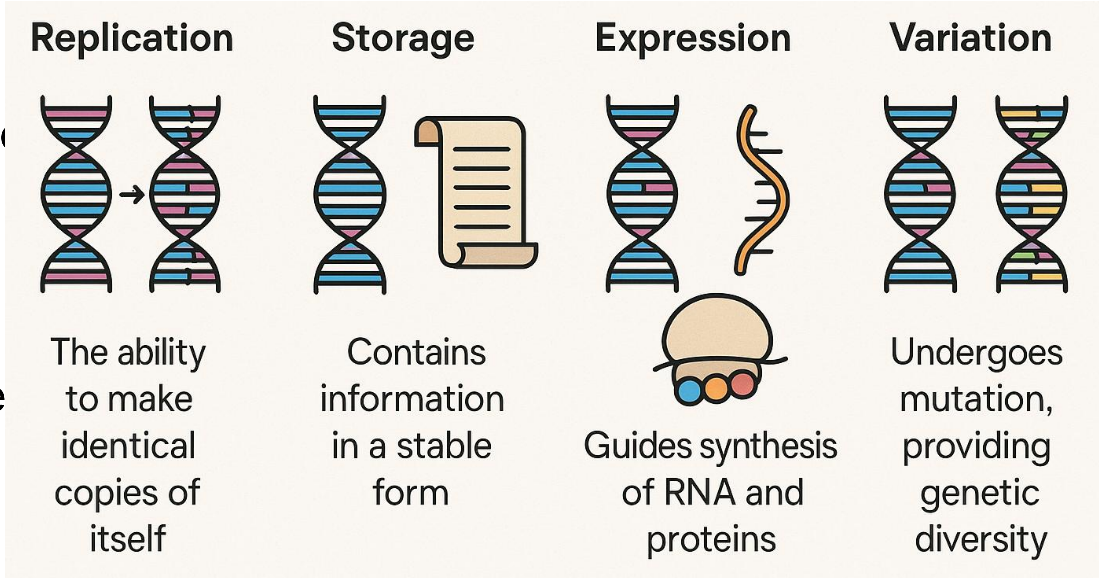
Functions of Genetic Material:

a) Replication – The ability to make identical copies of itse

b) Storage – Contains information in a stable form.

c) Expression – Guides synthesis of RNA and proteins.

d) Variation – Undergoes mutation, providing genetic dive



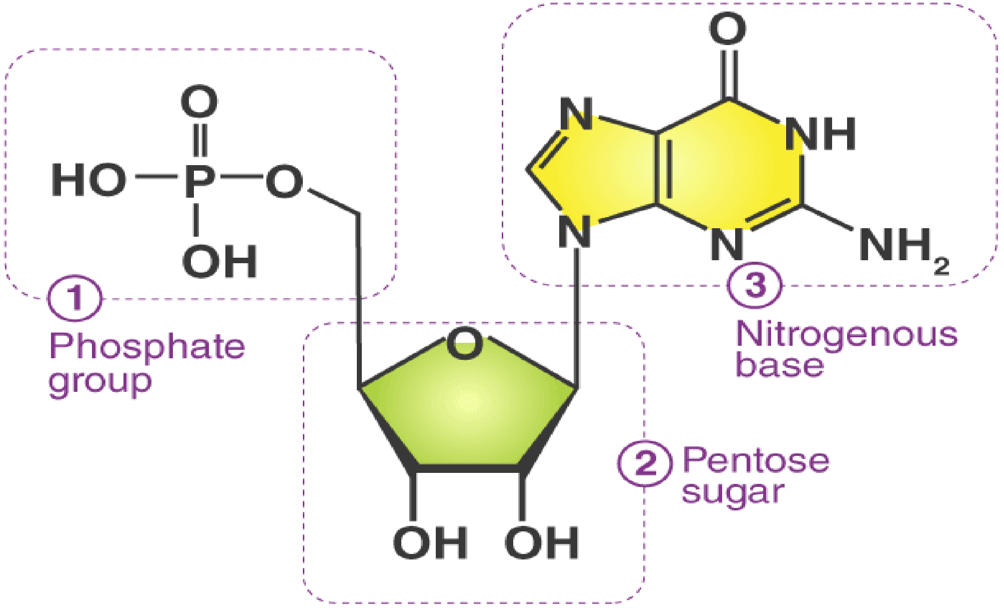
Introduction: The Genetic Material

- Historical Background:

Year	Scientist(s)	Discovery
1928	Frederick Griffith	Demonstrated transformation in Streptococcus pneumoniae, suggesting a “transforming principle.”
1944	Avery, MacLeod & McCarty	Identified **DNA** as the transforming substance.
1952	Hershey–Chase	Confirmed **DNA** as genetic material using bacteriophage T2 and radioisotope labeling.

Chemical Composition of Nucleic Acids

- Both DNA and RNA are **polynucleotides**, composed of **nucleotide monomers.**
  - **Each Nucleotide Has Three Components:**
- **Nitrogenous Base**
  - **Purines:** Adenine (A) and Guanine (G) — double-ring structures.
  - **Pyrimidines:** Cytosine (C), Thymine (T, in DNA), and Uracil (U, in RNA).
- **Pentose Sugar**
  - **DNA:** Deoxyribose (no –OH at 2′ carbon).
  - **RNA:** Ribose (has –OH at 2′ carbon).
- **Phosphate Group:** Attached to the 5′ carbon of the sugar via
  - **phosphoester bond:** Responsible for the negative charge of nucleic acids.



Structure of Nucleotides and Nucleosides

What are Nucleotides and Nucleosides?

- **Nucleic acids (DNA and RNA)** are made of small units called **nucleotides.**
- Each **nucleotide** has **three parts**:
  - **Nitrogen base**
  - **Sugar**
  - **Phosphate group**
- If the phosphate group is **missing**, it is called a **nucleoside.**

◦ **A. Nitrogen Bases:**

◦ There are **two types** of nitrogen bases:

Type	Bases	Found in
Purines	Adenine (A), Guanine (G)	DNA & RNA
Pyrimidines	Cytosine (C), Thymine (T), Uracil (U)	T in DNA, U in RNA

◦ **B. Sugar**

◦ The sugar connects the base and phosphate.

◦ Two kinds of sugars:

  ◦ **Deoxyribose** → in **DNA** (no –OH on 2′ carbon)

  ◦ **Ribose** → in **RNA** (has –OH on 2′ carbon)

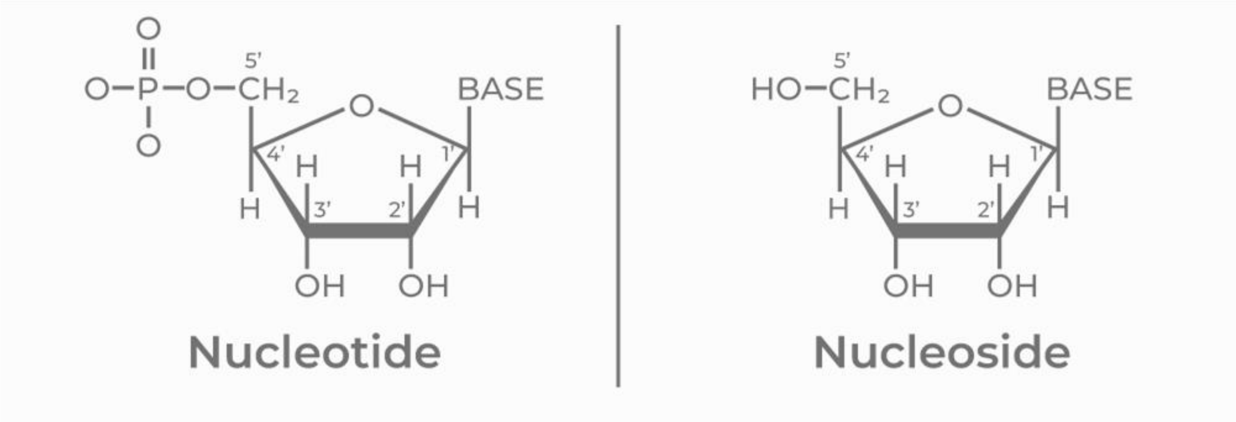
Structure of Nucleotides and Nucleosides

C. Phosphate Group

- Gives DNA and RNA their **negative charge.**
- Connects one nucleotide to the next to form a **chain** (the backbone of DNA/RNA).

D. Nucleoside vs. Nucleotide

Component	Nucleoside	Nucleotide
Contains	Base + Sugar	Base + Sugar + Phosphate
Example	Adenosine	Adenosine monophosphate (AMP)



E. Importance

- **Nucleosides** are building blocks for nucleotides.
- **Nucleotides** are the **basic units of DNA and RNA** and also provide **energy** (like ATP).

DNA Structure

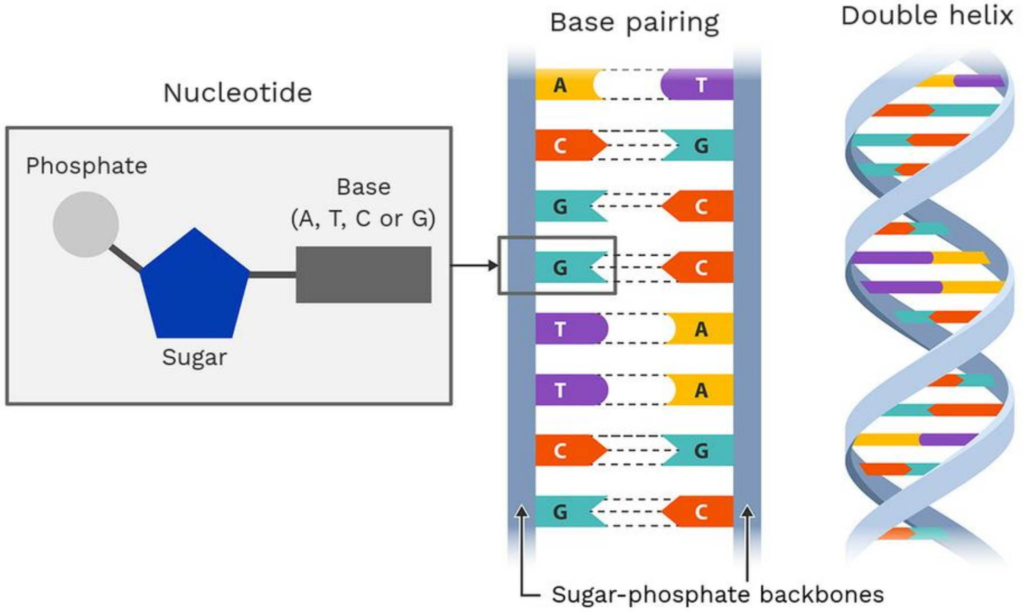
What is DNA?

DNA (Deoxyribonucleic Acid) is the molecule that carries **genetic information.**

- It tells cells how to make proteins and controls inherited traits.

A. Building Blocks of DNA

- DNA is made of **nucleotides**, and each nucleotide has three parts:
  - **Phosphate group**
  - **Sugar (deoxyribose)**
  - **Nitrogen base** – Adenine (A), Thymine (T), Guanine (G), or Cytosine (C)



B. Shape of DNA

- DNA has a **double helix shape** – like a **twisted ladder.**
- The **sides** of the ladder are made of **sugar and phosphate.**
- The **steps** are pairs of **bases.**

DNA Structure

C. Base Pairing

- Bases always pair in a **specific way**:
  - **A** pairs with **T** (2 hydrogen bonds)
  - **G** pairs with **C** (3 hydrogen bonds)
- This is called **complementary base pairing.**

D. DNA Strands

DNA has **two strands** that run in **opposite directions.**

- One goes from **5′ to 3′**, and the other from **3′ to 5′**.
- This is called **antiparallel** arrangement.

E. Bonds in DNA

- **Hydrogen bonds** connect the bases.
- **Phosphodiester bonds** connect the sugar and phosphate along each strand.

Feature	Description
Shape	Double helix (twisted ladder)
Base pairs	A–T, G–C
Bonds	Hydrogen and phosphodiester
Strands	Antiparallel
Function	Stores genetic information

Base Pairing Rules

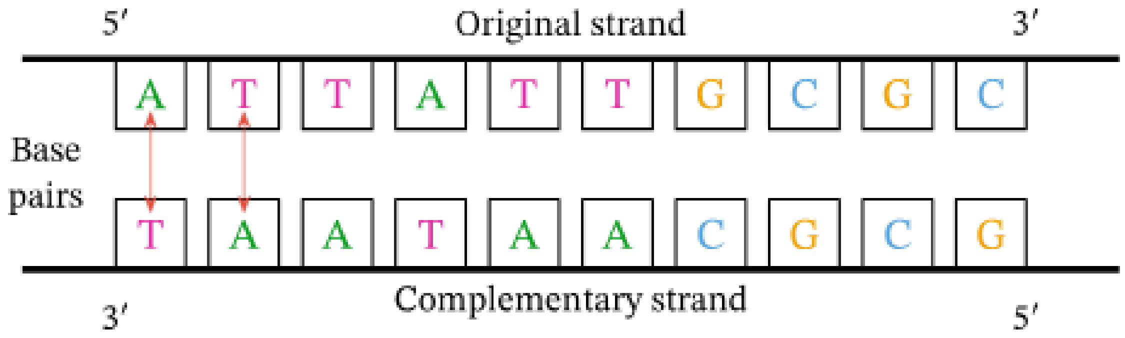
What is Base Pairing?

- **Base pairing** means that the nitrogen bases in DNA (and RNA) connect or "pair" with each other in a **specific and predictable way.**
- This pairing keeps the **two DNA strands together** and ensures **accurate replication and transcription.**

A. Complementary Base Pairing

In DNA, the bases pair as follows:

Base	Pairs With	Number of Hydrogen Bonds
Adenine (A)	Thymine (T)	2
Guanine (G)	Cytosine (C)	3



Hydrogen bonds are weak individually, but thousands of them make the DNA molecule stable and easy to unzip during replication.

Base Pairing Rules

B. Base Pairing in RNA

In **RNA**, there is **no thymine (T)**. Instead:

- **Adenine (A)** pairs with **Uracil (U)**.
- **Guanine (G)** still pairs with **Cytosine (C)**.

So the rule in RNA is: 👉 **A–U** and **G–C**

C. Importance of Base Pairing

Base pairing is essential because it:

1. **Maintains the double helix structure** of DNA.
2. **Allows replication** — each strand can serve as a **template** to make a new one.
3. **Ensures genetic accuracy** — the same sequence of bases is copied every time.
4. **Controls transcription** — mRNA is made using complementary base pairing from the DNA template.

Sugar–Phosphate Backbone

A. What is the Sugar–Phosphate Backbone?

- The **sugar–phosphate backbone** forms the **structural framework** of DNA and RNA molecules.
- It acts like the **“sides” of a ladder**, giving the molecule strength and stability.
- The **nitrogen bases (A, T, G, C or U)** stick out from this backbone like “rungs.

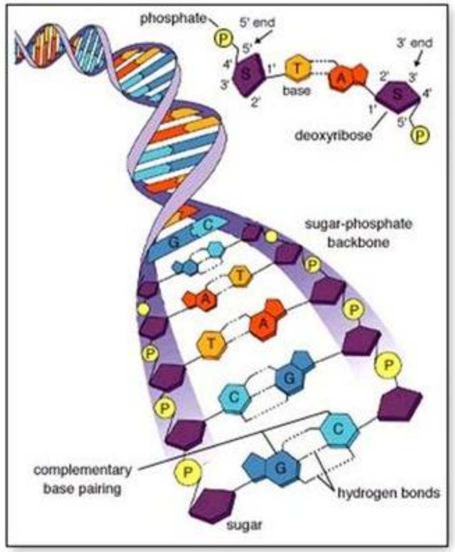
B. Components

- Each backbone is made of:

1) **Pentose sugar**
   - **Deoxyribose** in DNA (no –OH group at 2′ carbon).
   - **Ribose** in RNA (has –OH at 2′ carbon).
2) **Phosphate group**
   - Links the sugars of two neighboring nucleotides.

- These two parts alternate — **sugar–phosphate–sugar–phosphate** — throughout the molecule.

Sugar-Phosphate backbone



- Sugar and phosphate molecules form the backbone of DNA (sides of the ladder)
- Nitrogenous bases are attached to the sugar (steps of the ladder)

RNA Structure

A. What is RNA?

- **RNA (Ribonucleic Acid)** is a **nucleic acid** that plays a central role in **gene expression** — it helps convert the genetic information in DNA into proteins.
- Unlike DNA, RNA is usually **single-stranded**, but it can fold into complex shapes through **base pairing** within the same molecule.

B. Components of RNA

- Each RNA nucleotide consists of:
  - **Ribose sugar** – contains an **–OH group at the 2′ carbon**, which makes RNA **more reactive** and **less stable** than DNA.
  - **Phosphate group** – forms the sugar–phosphate backbone.
  - **Nitrogenous bases:**
  - **Adenine (A)**, **Guanine (G)**, **Cytosine (C)**, **Uracil (U)** → replaces **Thymine (T)** found in DNA.
- Because of uracil and the extra –OH group, RNA differs chemically and structurally from DNA.

RNA Structure

C. Structure of RNA Molecule

1) **Single-Stranded Nature**
   - RNA typically exists as a **single polynucleotide chain.**
   - However, parts of the strand can fold back and **form base pairs with itself**, creating hairpins, loops, and double-stranded regions.

2) **Base Pairing in RNA**
   - **A pairs with U** (2 hydrogen bonds).
   - **G pairs with C** (3 hydrogen bonds).
   - These pairings help RNA molecules fold into **three-dimensional shapes** needed for their function.

3) **3′ and 5′ Ends**
   - Like DNA, RNA has **directionality**: a **5′ end** with a phosphate and a **3′ end** with an –OH group.

D. Comparison: DNA vs RNA

Feature	DNA	RNA
Sugar	Deoxyribose (no –OH on 2′ C)	Ribose (has –OH on 2′ C)
Bases	A, T, G, C	A, U, G, C
Strands	Double-stranded	Usually single-stranded
Stability	Very stable	Less stable, breaks down faster
Function	Stores genetic information	Expresses genetic information (transcription & translation)

RNA Structure

D. Types of RNA and Their Functions

Type of RNA	Full Name	Function
mRNA	Messenger RNA	Carries genetic code from DNA to ribosome for protein synthesis
tRNA	Transfer RNA	Brings amino acids to the ribosome during translation
rRNA	Ribosomal RNA	Forms part of the ribosome's structure and catalyzes peptide bond formation
snRNA	Small nuclear RNA	Involved in RNA splicing (removing introns)
miRNA / siRNA	Micro / Small interfering RNA	Regulates gene expression by silencing or degrading mRNA

Denaturation and Renaturation of DNA

A. What is DNA Denaturation?

- **Denaturation** means the **separation of the two DNA strands** when the **hydrogen bonds** between base pairs are broken.
- The **sugar–phosphate backbone** remains intact — only the **weak hydrogen bonds** are disrupted.
- This causes **loss of the double-helix structure**, converting DNA into **single strands.**

B. Causes of Denaturation

- DNA can be denatured by:

1. **Heat (thermal denaturation):**
   - Increasing temperature causes the hydrogen bonds between base pairs to break.
   - The point where half of the DNA molecules are single-stranded is called the **melting temperature (T_m).**
   - DNA rich in **G≡C pairs** has a **higher T_m** because **G–C has 3 hydrogen bonds** (stronger) while **A–T has 2.**
2. **Extreme pH (chemical denaturation):**
   - Very **acidic or basic conditions** break hydrogen bonds and ionize the bases.
   - This also leads to strand separation.
3. **Chemical agents:**
   - **Urea** and **formamide** can weaken hydrogen bonds and denature DNA at lower temperatures.

Denaturation and Renaturation of DNA

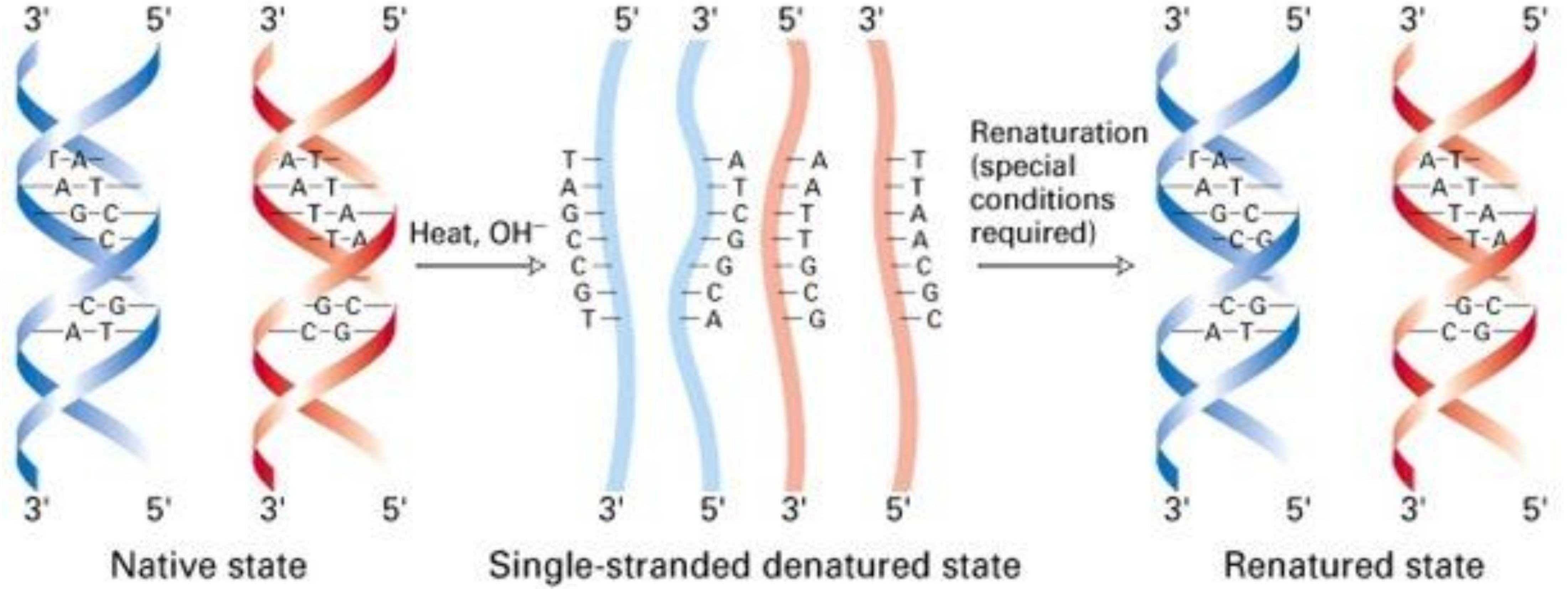
C. What is Renaturation (Reannealing)?

- **Renaturation** is the **rejoining of two complementary DNA strands** after denaturation.
- When the denatured DNA is **slowly cooled**, the complementary bases **realign** and **hydrogen bonds** reform.
- The DNA returns to its **native double-helix structure.**

D. Biological and Laboratory Importance

1. **DNA Replication:**
   - During replication, DNA naturally denatures to allow new strands to form.
2. **Transcription:**
   - Denaturation exposes the DNA template so that RNA can be synthesized.
3. **Molecular Biology Techniques:**
   - **PCR (Polymerase Chain Reaction):** DNA is repeatedly **denatured and renatured** to make millions of copies.
   - **Hybridization assays (Southern or Northern blot):** Depend on **reannealing** of complementary DNA or RNA strands.

Denaturation and Renaturation of DNA



Summary

- DNA and RNA are the fundamental molecules of life that store, transmit, and express genetic information.
- DNA's double-helix structure ensures stable inheritance, while RNA's versatility enables protein synthesis and gene regulation.
- Understanding their structure, base pairing, and behavior under denaturation forms the basis of modern molecular biology and biotechnological advances.

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