# Lesson 01: Genetic material

**The course plan :**

*1. Chemical nature of the genetic material*

*2. Structure of nucleic acids (DNA-RNA)*

*3. DNA replication: in prokaryotes and eukaryotes*

*4. Chromosome organization*

**Introduction :**

Genetics is the science that studies heredity and genes in living beings, it is a sub-discipline of biology.

Today, genetics has diversified into several different branches such as:

• developmental genetics• developmental genetics

• medical genetics

• genomics

• quantitative genetics

• population genetics

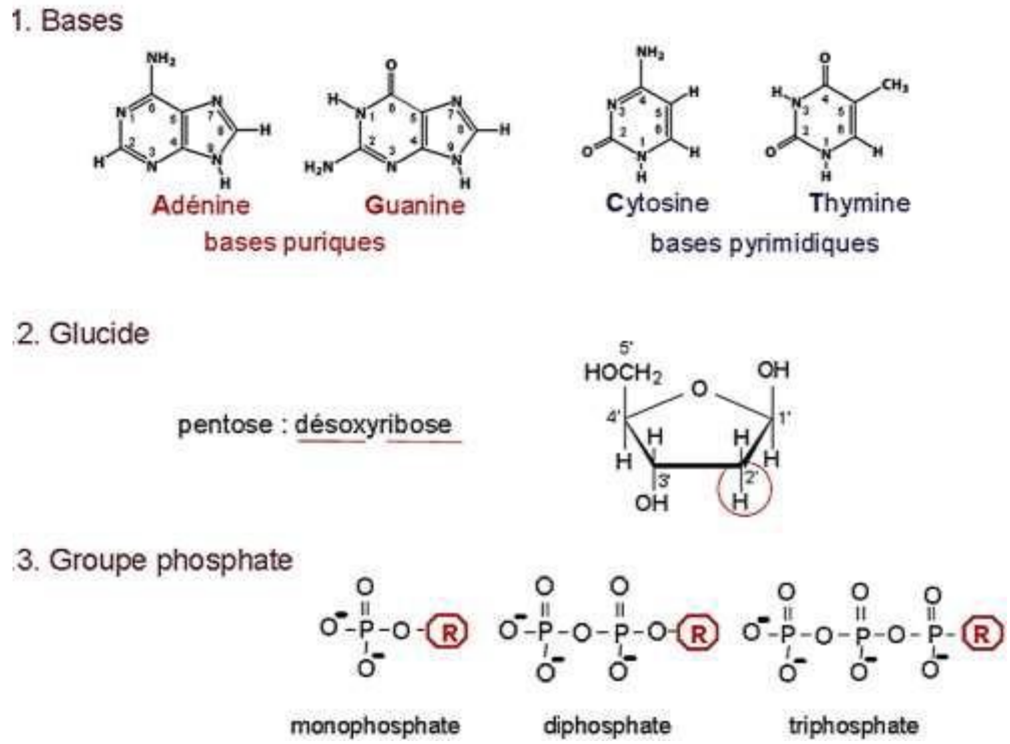
## 1. Chemical Nature of the Genetic Material (Nucleic Acids)

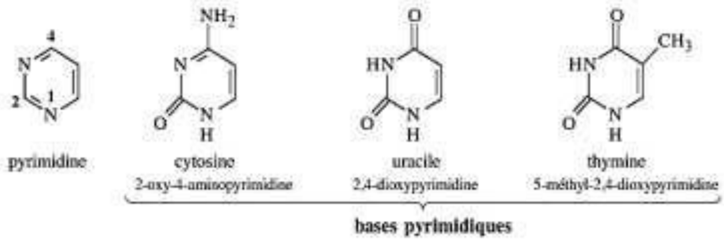
### 1-1- DNA (deoxyribonucleic acid)

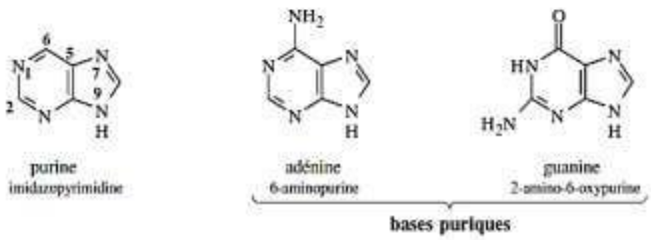
The basic unit of deoxyribonucleic acid (DNA) is the nucleotide.

A nucleotide is composed of three elements:

- A nitrogenous base: there are four different bases
  - Two bases puric acid : Adenine (A) Guanine (G)
  - Two bases pyrimidines : Cytosine (C) And Thymine (T)
- A sugar : deoxyribose called pentose (molecule with five carbons)
- A phosphate group ($PO_4$ )

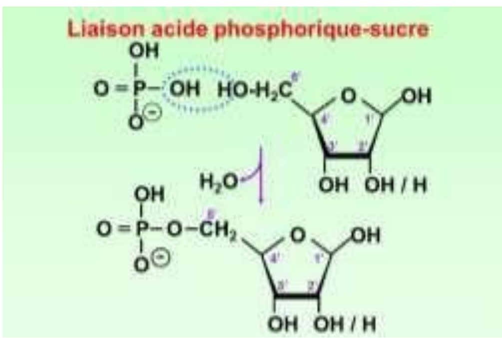



**A nucleoside** is formed from a sugar linked to a nitrogenous base by glycosidic bond**.**

**The nucleotide** is a nucleoside linked to a phosphate group through a phosphoester bond.



Thus, we obtain a nucleotide monophosphate, diphosphate and triphosphate.

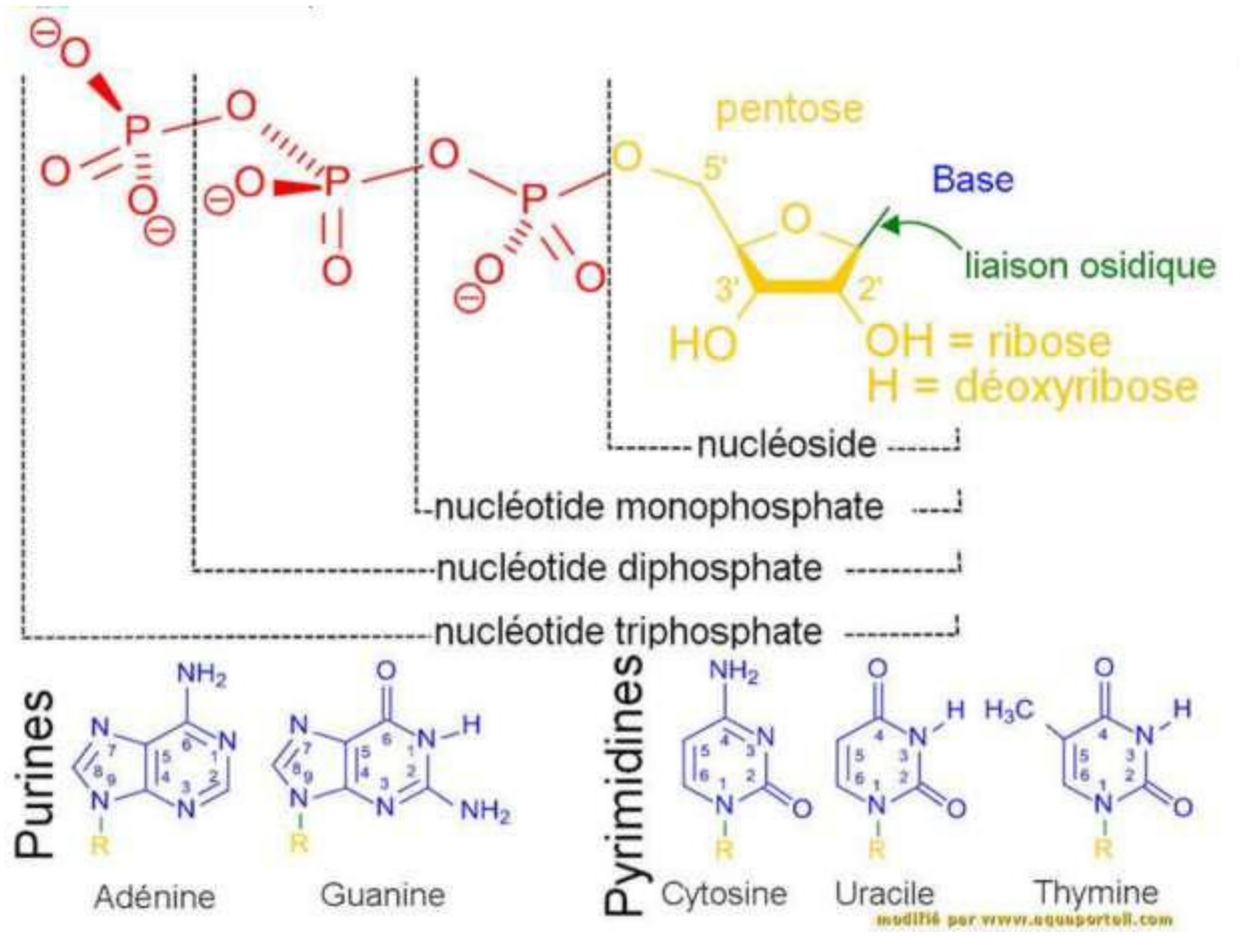



**Figure 1 : Chemical composition of a nucleotide**

### 1-2- RNA (acid ribonucleic acid)

Another class of nucleic acids called ribonucleic acid (RNA). It acts an intermediate between DNA and proteins. It is synthesized in the nucleus from DNA during transcription.

Its chemical nature differs slightly from DNA in the following ways:

- RNA contains ribose sugars instead of deoxyribose.
- RNA contains the pyrimidine uracil (U) instead of thymine (T). U pairs with adenine (A).

## 2- Structure of the nucleic acids

### 2- 1- DNA (acid deoxyribonucleic acid)

Nucleotides in a chain are connected by phosphodiester bonds oriented from 3' to 5' (between the phosphate group of one nucleotide and the deoxyribose of another nucleotide). They can form long polynucleotide chains.

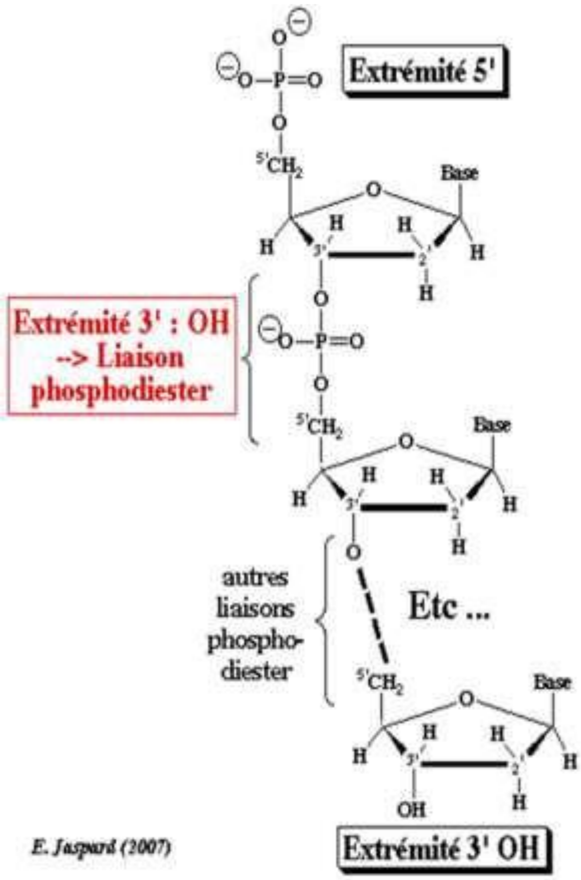
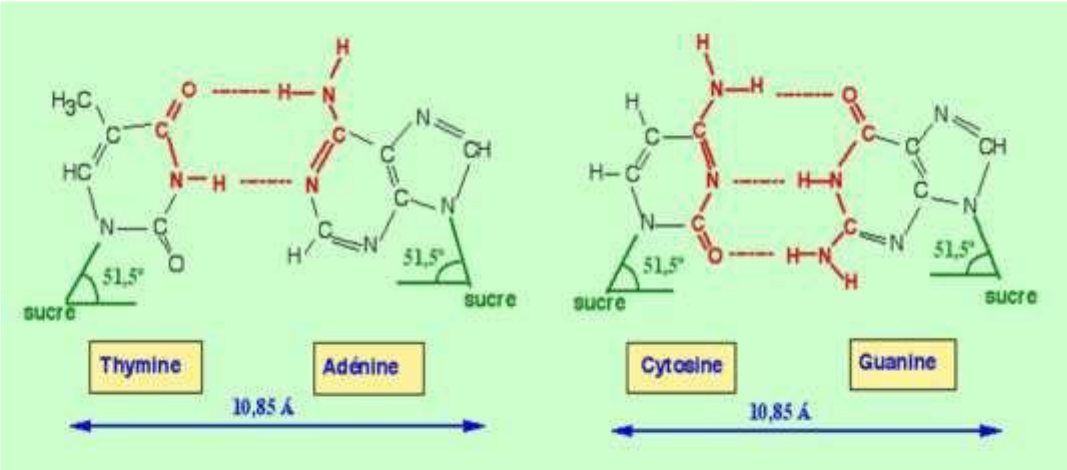



**Figure 2: A chain of polynucleotides**

DNA consists of two antiparallel (opposite orientation) polynucleotide chains**:**

- The two strands are held together by weak hydrogen bonds between bases that form pairs: A with T (two hydrogen bonds), and C with G (three hydrogen bonds). Purines always pair with pyrimidines, and vice versa. The two strands are therefore complementary.
- One chain is oriented from 3' to 5', while the other runs in the opposite direction (5' to 3').

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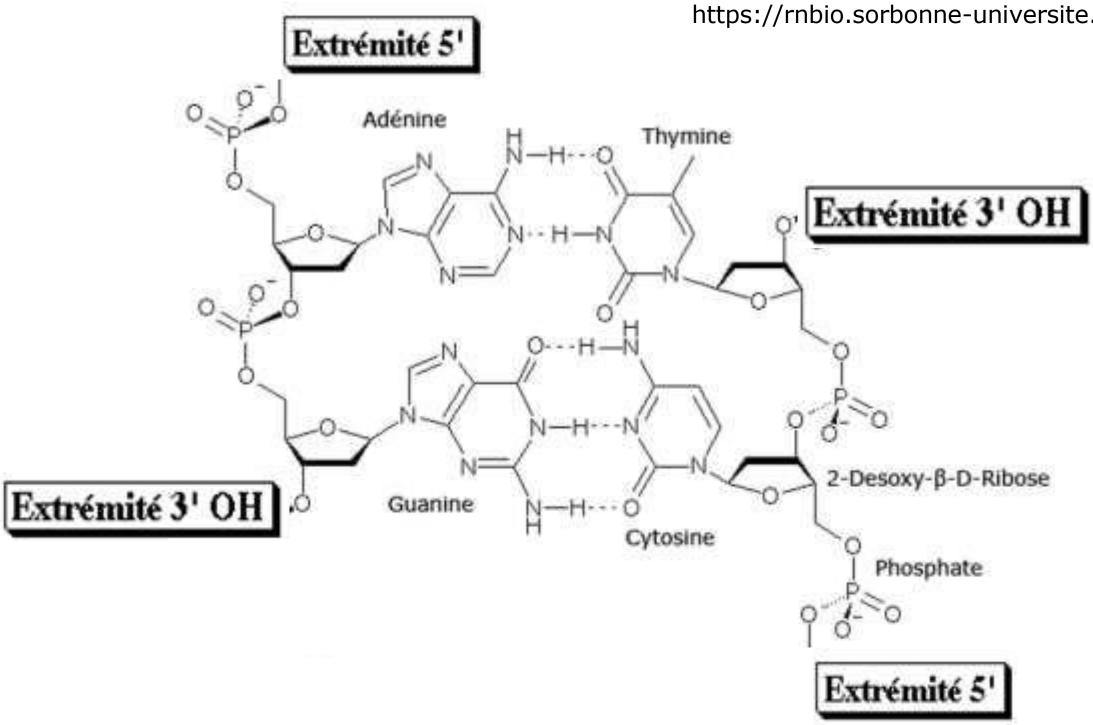



**Figure 3 : Two complementary polynucleotide chains**

The two strands coil around each other, forming a double helix (double-stranded structure). The bases are inside the structure, while the sugar-phosphate backbone lies on the outside. Once unwound, a DNA molecule can reach up to 7 cm in length. Its diameter is 2 nanometers (nm), the pitch of one turn is 3.4 nm and includes 10 base pairs (the distance between two bases on the same strand is 0.34 nm).

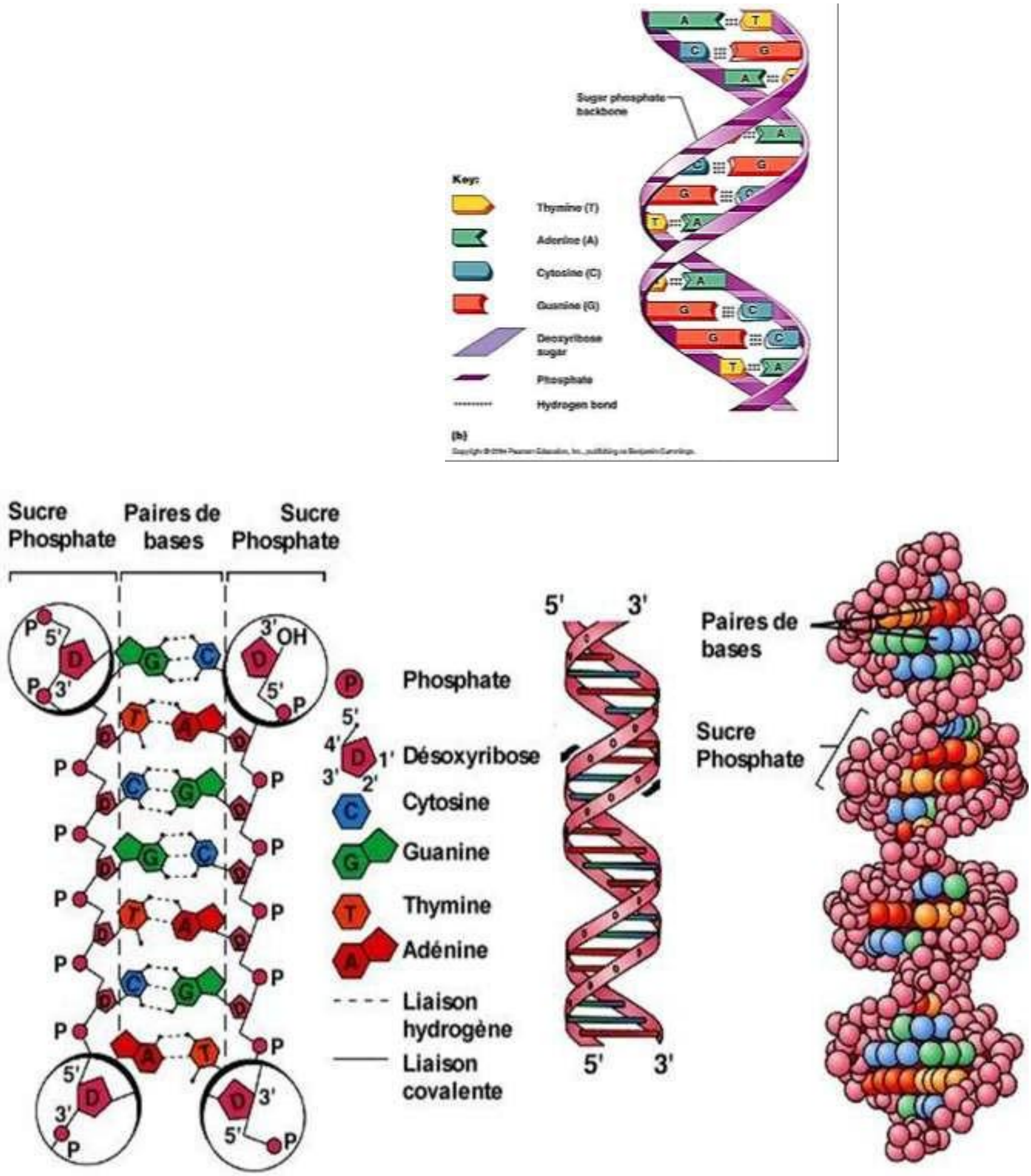



**Figure 4: DNA structure**

Each cell of an individual contains the same DNA molecules in its nucleus (except in cases of disease, mutation, etc.).

DNA is fragile, and the two strands can easily separate (denaturation) with moderate heating (<50°C). They can re-anneal (renaturation) when the temperature decreases.

- **Chargaff 's Rule**

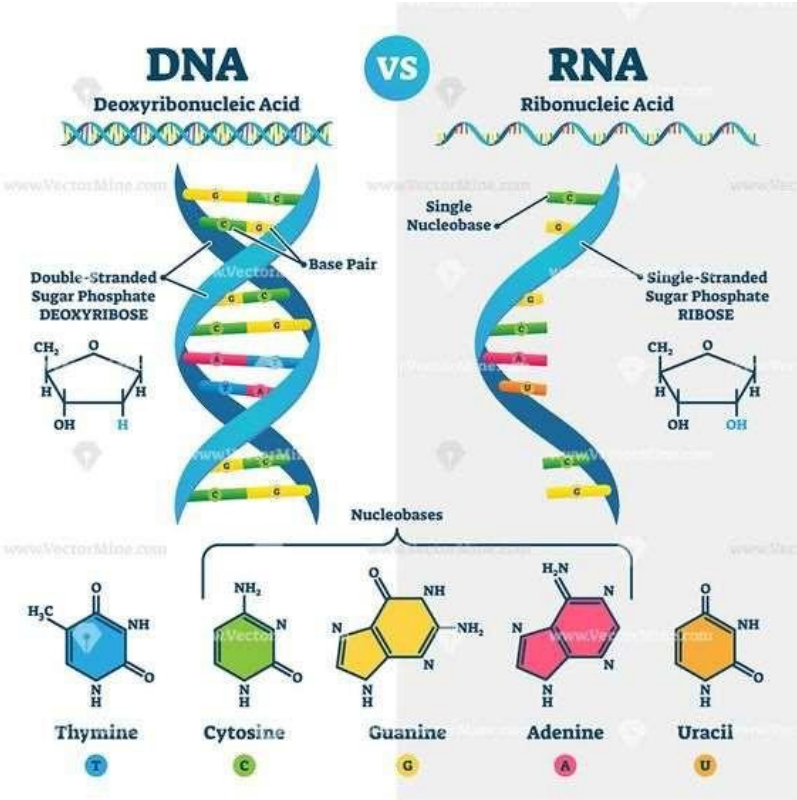
In the 1940s, Chargaff observed that:

- Regardless of the species, DNA always contains as many purines as pyrimidines, i.e. (A + G) = (C + T)
- Thus, (A + G) / (C + T) = 1.
- Furthermore, the amount of thymine equals adenine (A/T = 1), and the amount of guanine equals cytosine (G/C = 1).

### 2-2- RNA (Ribonucleic Acid)

The structure of RNA differs from that of DNA in the following ways:

- Cellular RNA is usually single-stranded, whereas DNA is double-stranded. However, some viruses contain single-stranded DNA, while others contain single- or double-stranded RNA.
- RNA molecules are much shorter than DNA molecules.




**Differences between DNA and RNA**

## 3. Functions of the acids nucleic

### 3-1- DNA

DNA is a long polymer of thousands of nucleotide base pairs (bp). It is a macromolecule composed of repeating subunits (monomers) covalently bonded together.

Functions:

- Stores the genetic information of the cell and its organization, providing the instructions necessary for life.

- Ensures the transmission of genetic heritage from one generation to the next.

- Controls the synthesis of proteins necessary for life.

### 3- 2- RNA

Different RNAs play specific roles in protein synthesis:

- rRNA (ribosomal RNA): forms ribosomes together with proteins. rRNA is the most abundant RNA in the cell.
- mRNA (messenger RNA): carries genetic information from DNA to ribosomes, where it is translated into polypeptides.
- tRNA (transfer RNA): carries an amino acid at one end, complementary to a codon on the mRNA, following the rules of base pairing.

## 4. Organization of DNA in chromosome

In eukaryotes, the genome is divided into multiple linear chromosomes. The number of chromosomes varies among species.

| Animaux | | | | Végètaux | | | |
|---|---|---|---|---|---|---|---|
| Drosophile | 8 | Homme | 46 | Crocus | 6 | Tomate | 24 |
| Grenouille | 26 | Chimpanzé | 48 | Jacinthe | 8 | Riz | 24 |
| Hamster chinois | 22 | Vache | 60 | Pois | 14 | Lis | 24 |
| Chat | 38 | Cheval | 64 | Oignon | 16 | Tabac | 48 |
| Souris | 40 | Ane | 62 | Levure | 18 | Pomme de terre | 48 |
| Rat | 42 | Chien | 78 | Maïs | 20 | Fougère | 100 |
| Singe Rhésus | 42 | Poule | 78 | Haricot | 22 | | |
| Lapin | 44 | | | | | | |

A chromosome can consist of:

- One chromatid (in the G1 phase).

- Two sister chromatids (duplicated chromosome in G2 phase)

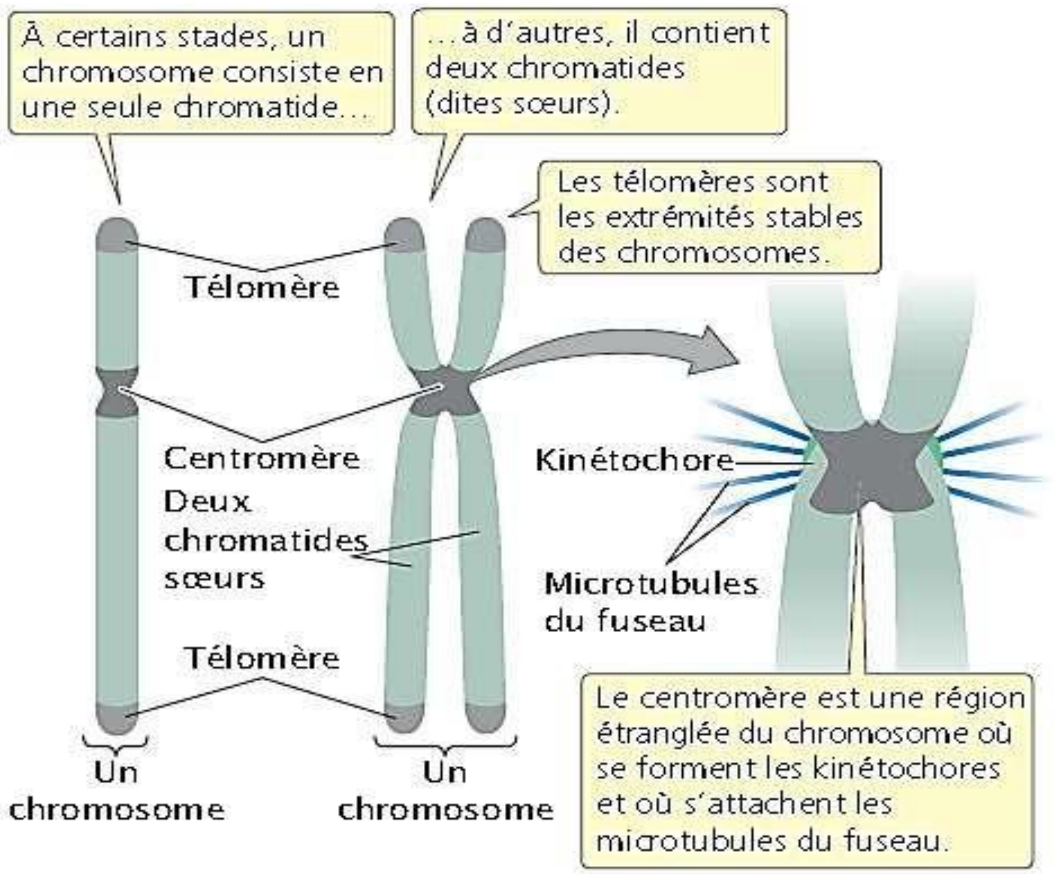
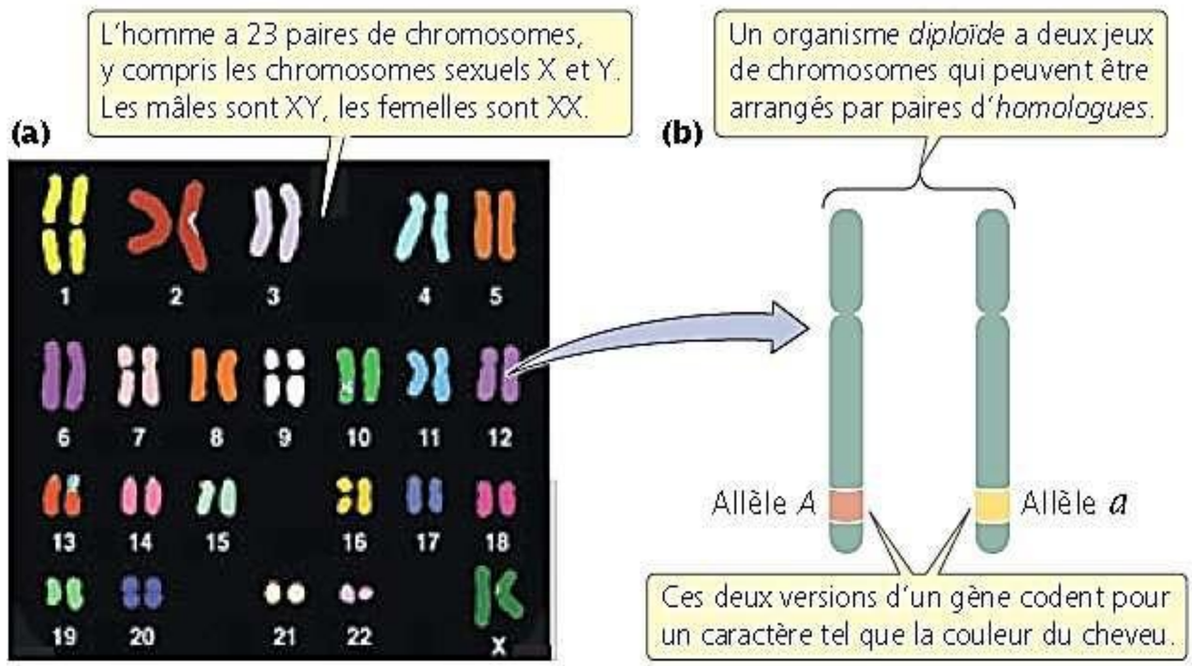


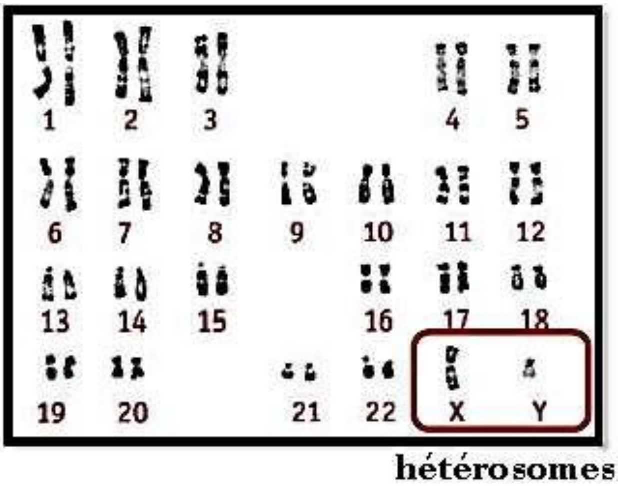

**Figure 5: Representative diagram of a metaphase chromosome**

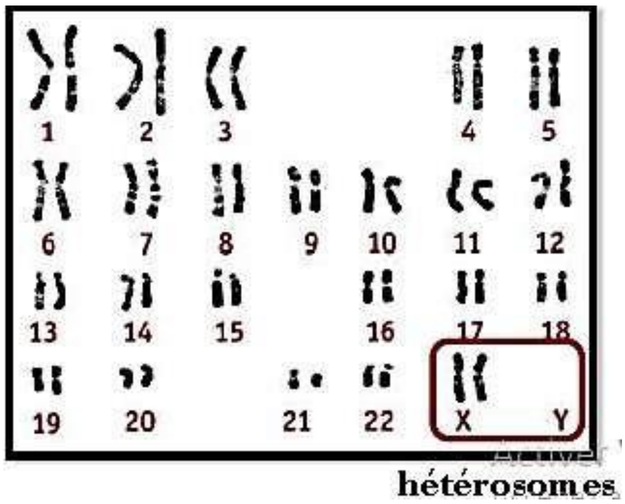


Eukaryotic cells are diploid, possessing two sets of chromosomes:



Some chromosome pairs differ morphologically between sexes: sex chromosomes **(heterosomes)**. Other pairs are **autosomes** (non-sex chromosomes)**.**

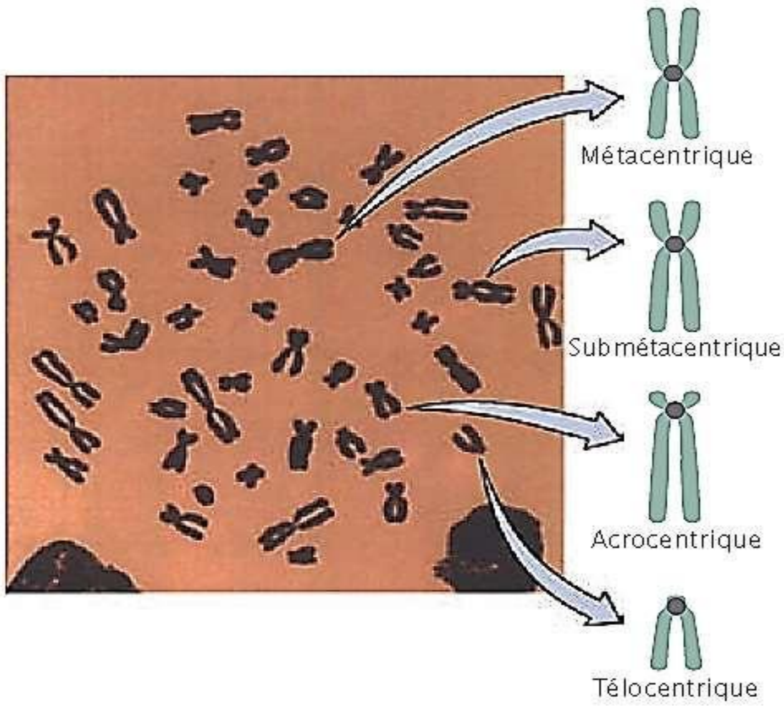



**Karyotype of the human** **karyotype of women**

**Figure 6 : Human karyotype**

Chromosome types depend on centromere position: **metacentric, submetacentric, acrocentric, and telocentric**.

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**Chromatin** = DNA + proteins. Proteins include:

- **Functional proteins** (transcription, replication, expression).

- **Structural proteins**, especially **histones**.

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Histones (H1, H2A, H2B, H3, H4) are rich in lysine and arginine, enabling DNA binding. DNA (147 bp) wraps around a histone octamer to form a nucleosome (first level of compaction). These repeat to form nucleofilaments, which condense into higher structures.

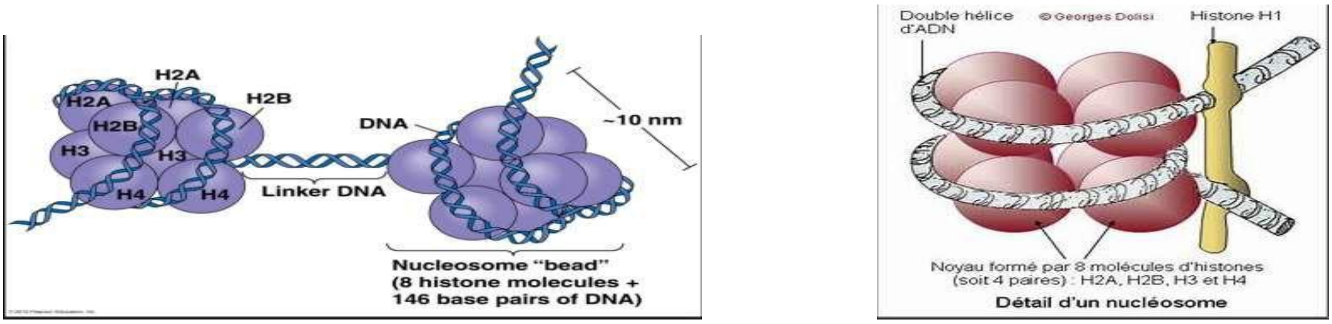
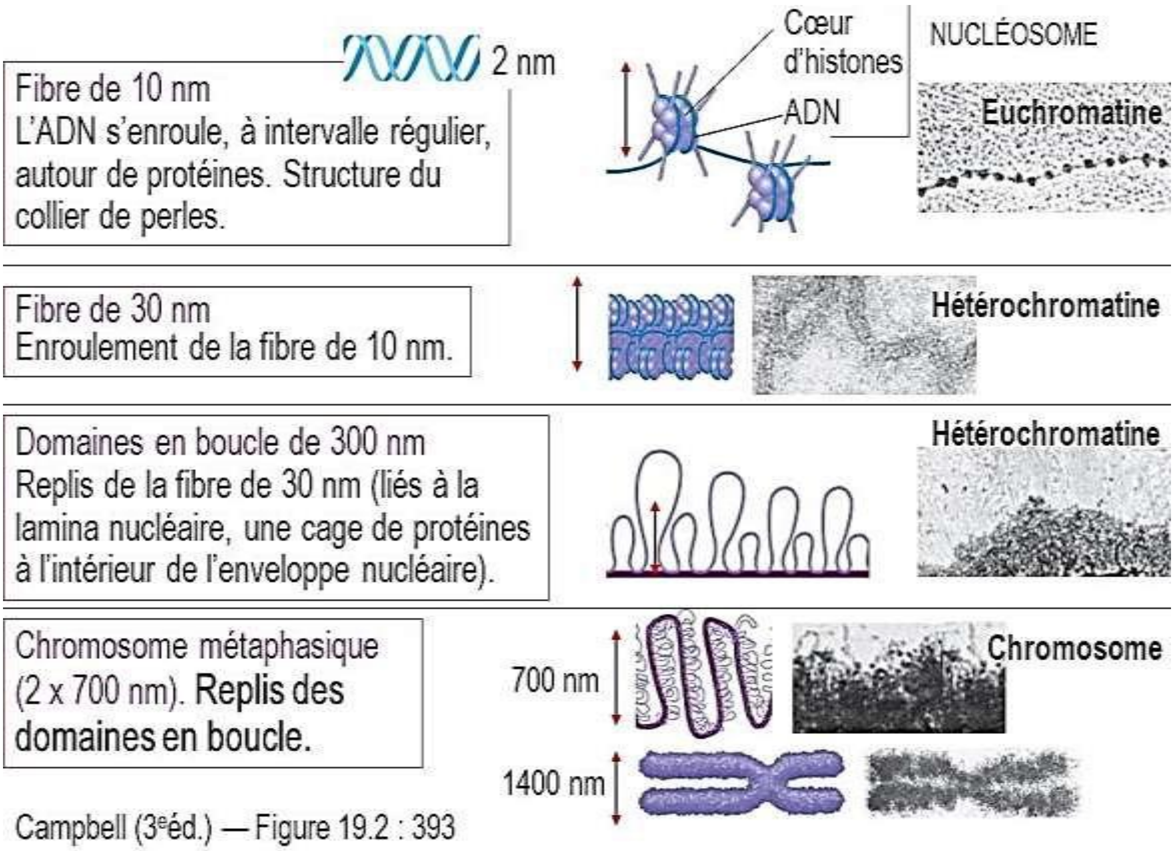



**Figure 7: Nucleosomal fiber = DNA + proteins**

It Chromatin exists in two forms:

- **Heterochromatin**: inactive, condensed, at the nuclear periphery.
- **Euchromatin**: active, dispersed in the nucleoplasm.

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- Le **nucléoplasme** contient : ADN, ARN et protéines
- **Hétérochromatine**: forme condensée de l'ADN, contient l'ADN qui est considérée comme en grande partie inactif (télomères, ADN ne contenant pas de gènes, gènes non transcrits).
- **Euchromatine**: Forme déballée de l'ADN qui est considérée comme contenant la portion active de l'ADN (gènes transcrits).
- **Nucléole**: contient les gènes de l'ARNr, site de synthèse des ribosomes (formés d'ARNr).

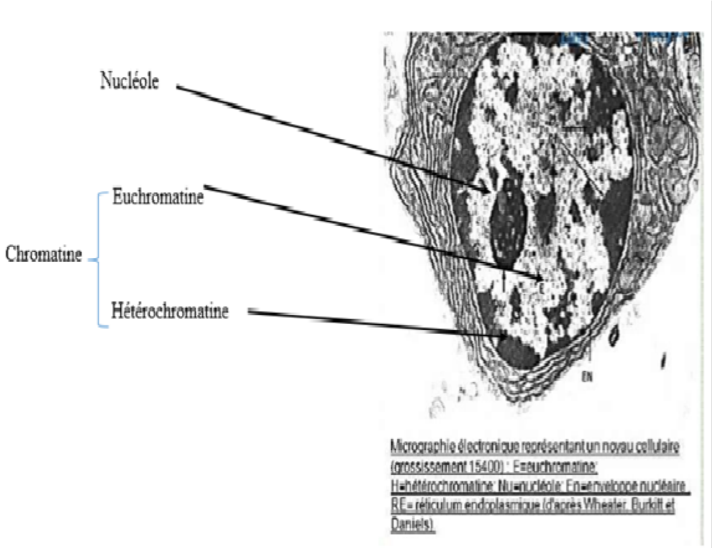



**Figure 08: Appearance of DNA in the nucleus of cells**

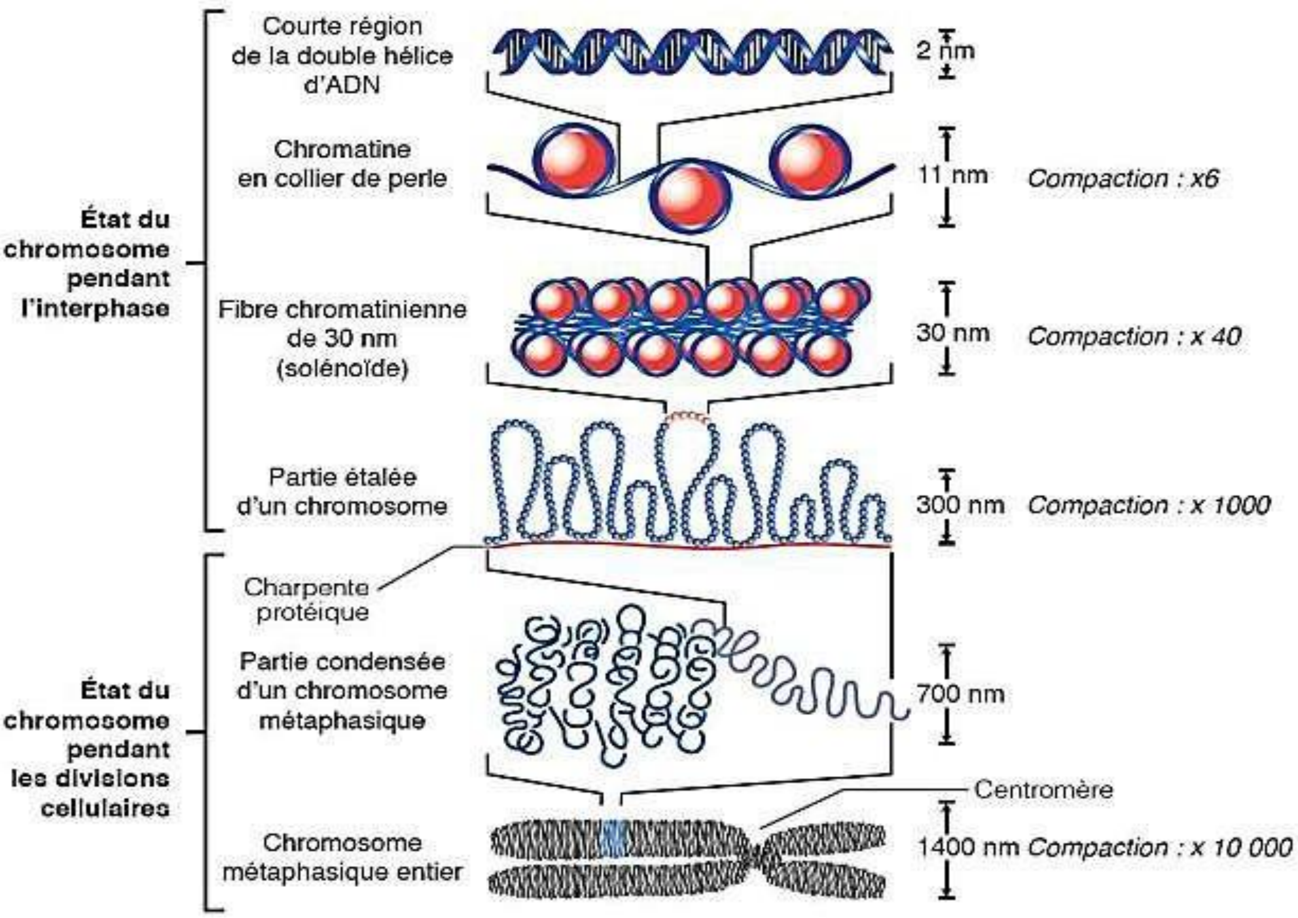



**Figure 9 Hypothetical structural levels of DNA organization in chromosomes during condensation in eukaryotes according to Seggara et *al* . (2014) *in* Tanguy (2017)**

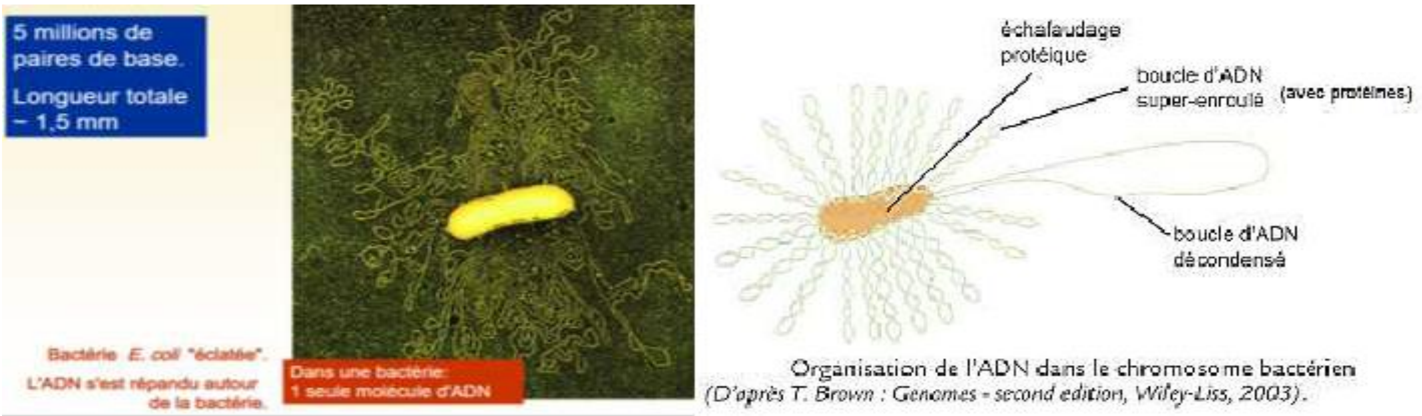



**Figure 10: Bacterial chromosome organization (Tangury , 2017)**

In prokaryotes, chromosomes consist of “naked” circular DNA (not associated with histones but with nucleoid-associated proteins, NAPs). DNA is organized into loops and compacted by supercoiling. Topoisomerases regulate coiling.

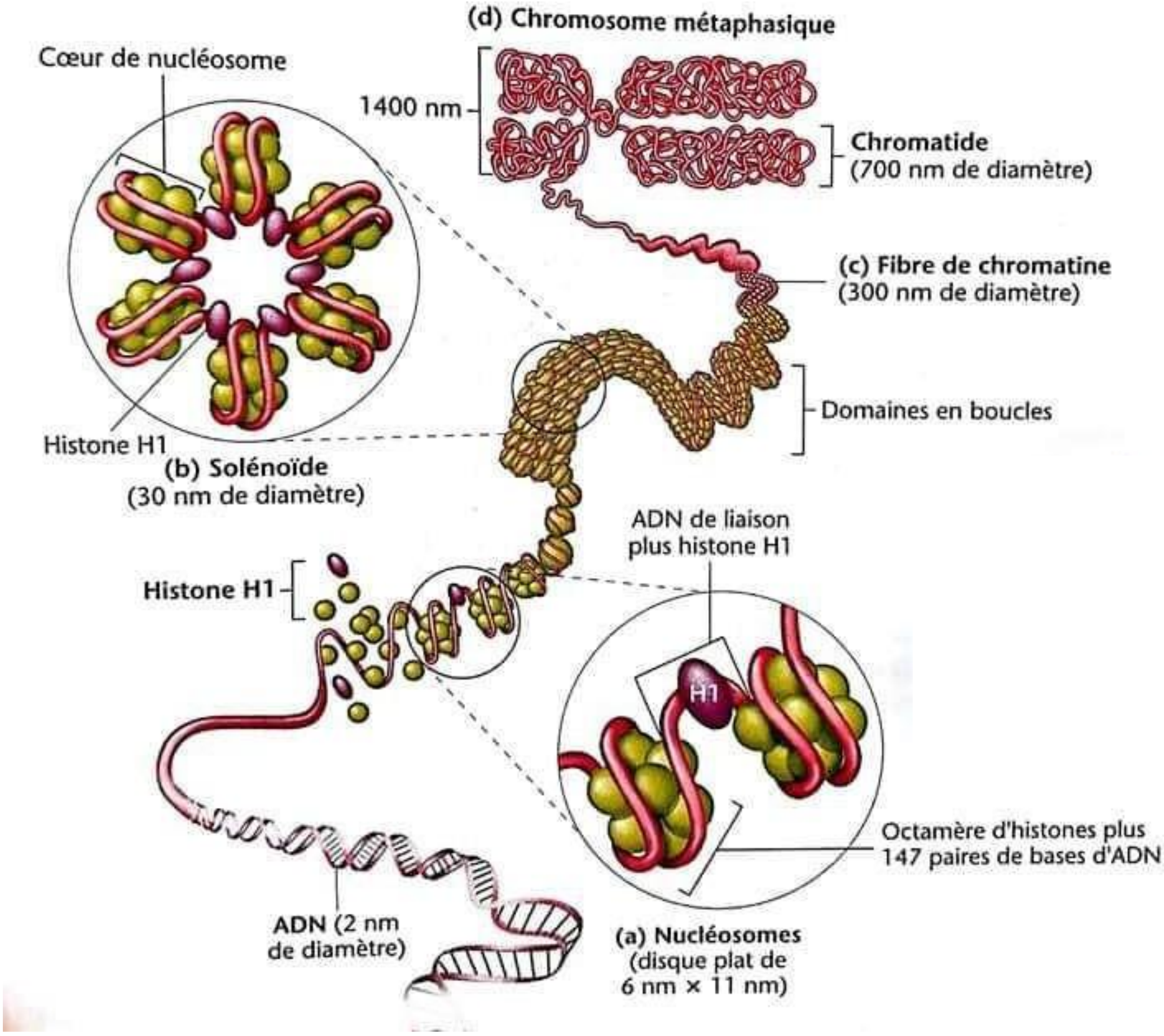
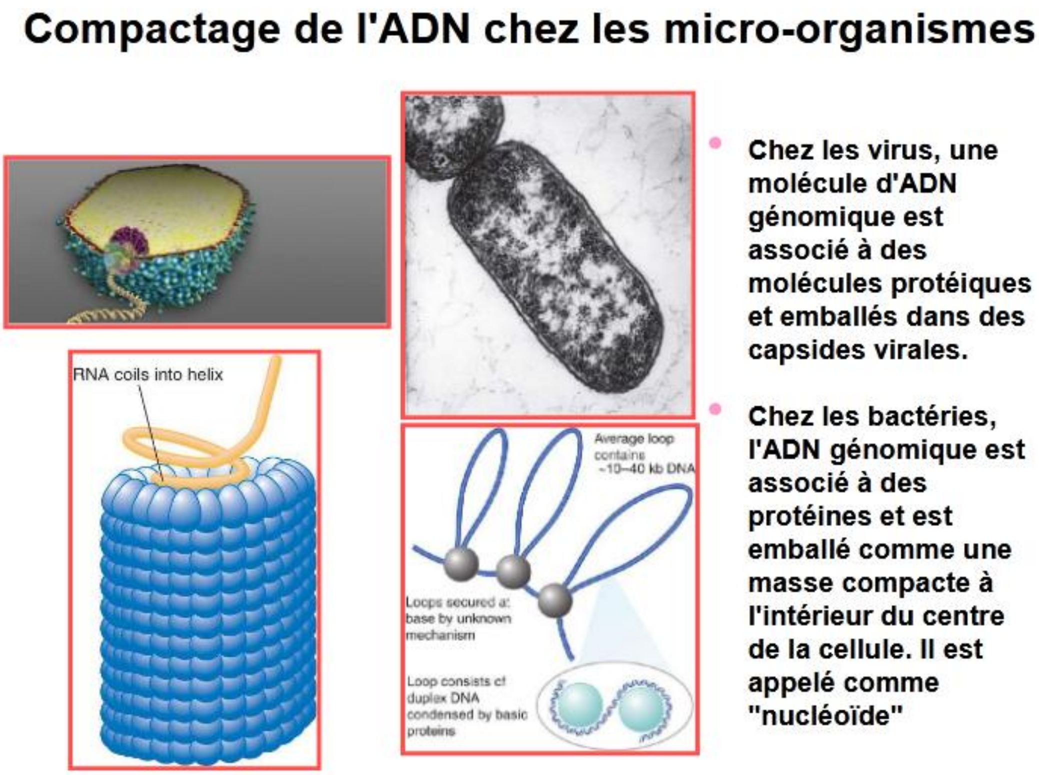


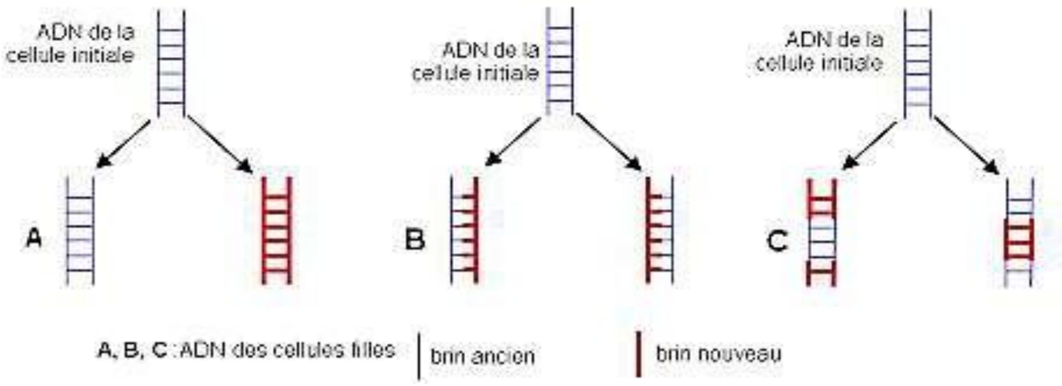

**Figure 11 : From DNA to the chromosome**

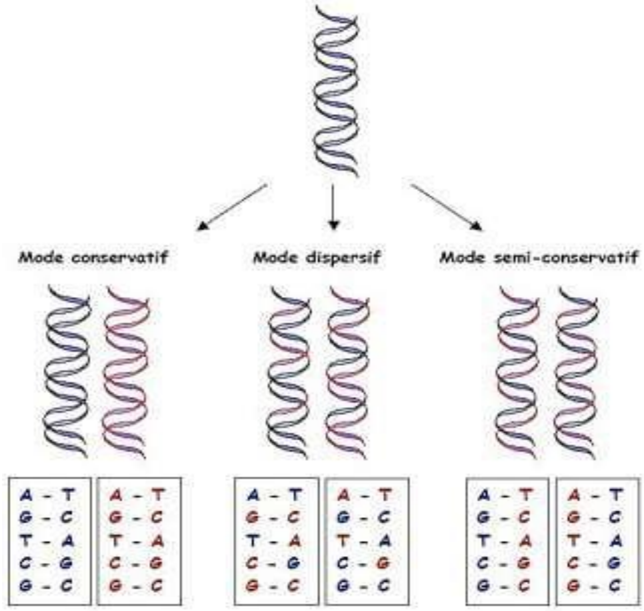


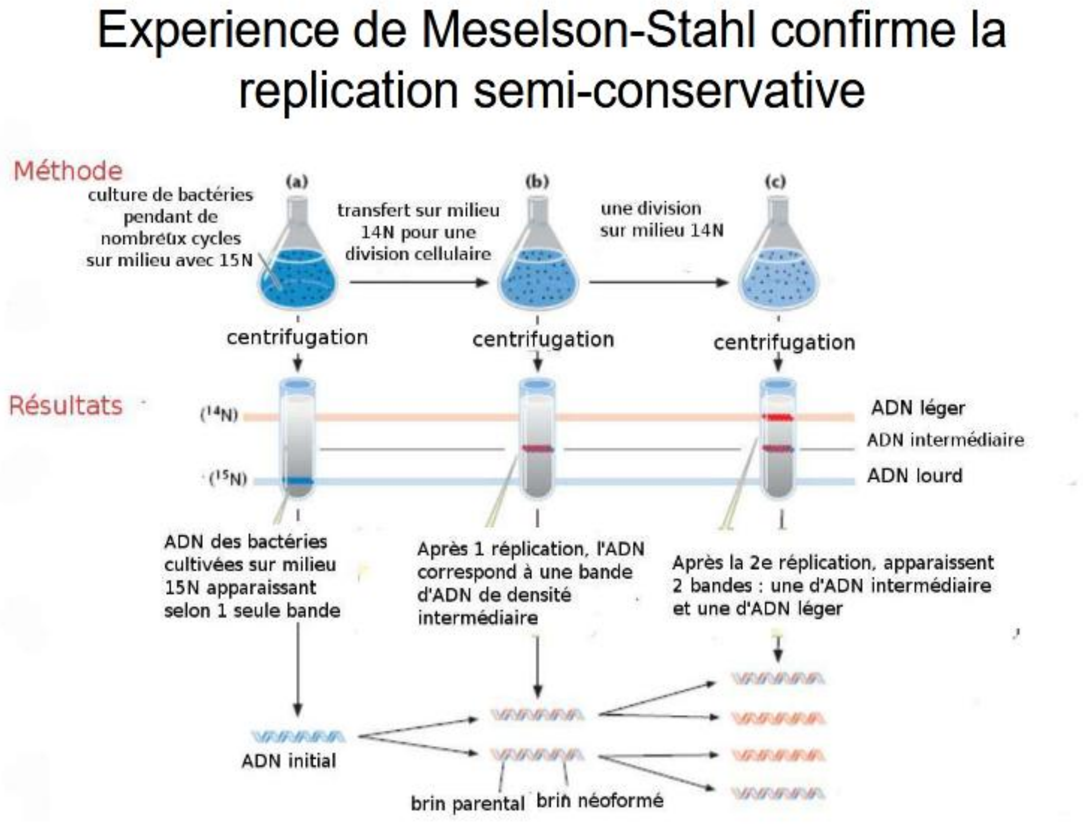

### 5. Replication of DNA

Replication produces two identical DNA molecules from one parental molecule, allowing genetic information to be transmitted to daughter cells during division.

Replication is semi-conservative: each new molecule contains one parental strand and one newly synthesized strand.






DNA replication occurs through the unwinding and separation of the parental DNA strands, each of which serves as a template.

The replication eye refers to the shape adopted by the DNA molecule during replication. Replication proceeds at both ends of the bubble (replication forks) until the entire molecule has been copied and the bubbles merge.

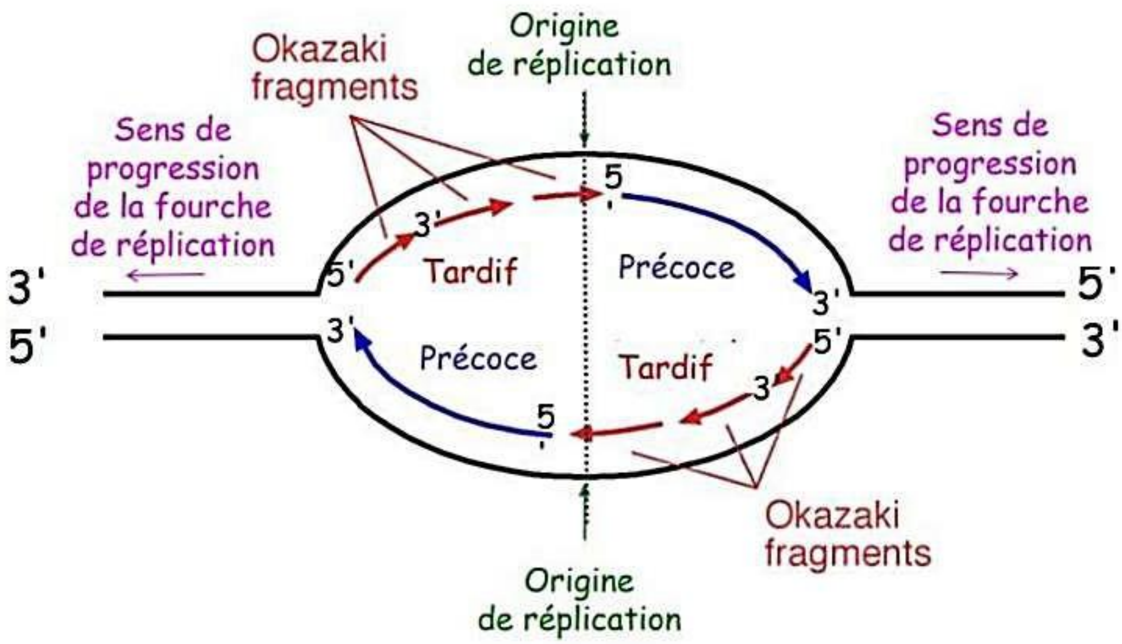


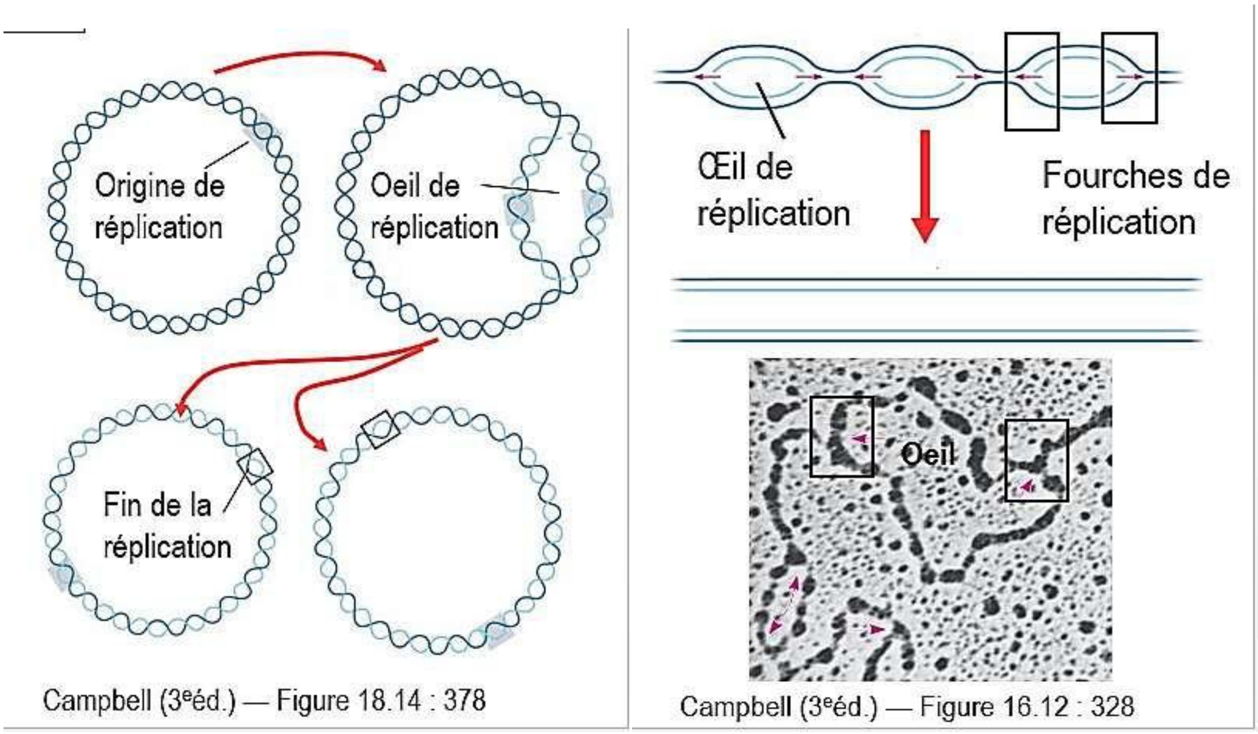

**Figure 13: Replication bubble with two opposing forks**

At the replication fork::

- One strand is synthesized in the same direction as the movement of the fork (continuous synthesis). This is called the **leading strand**.
- The other strand is synthesized in the opposite direction (discontinuous synthesis) as a series of short fragments called **Okazaki fragments**. This is the **lagging strand**.

**In prokaryotes**, the origin of replication is usually unique, and replication proceeds bidirectionally from this point.

**In eukaryotes**, replication begins at multiple origins. Hundreds or even thousands of replication bubbles may form simultaneously along the linear chromosomes.




**Prokaryotes** **Eukaryotes**

**Figure 14: Forks of replication : comparison between prokaryote and eukaryotic**

- ✓ **The progress of replication:**

- Each DNA molecule unwinds and separates into two strands, which serve as templates for DNA synthesis (hydrogen bonds between bases are broken).

- Replication proteins bind to the origins of replication, enabling the opening of the two DNA strands and the formation of replication forks.

- Deoxyribonucleoside triphosphates (dNTPs), already present in the nucleus, are incorporated at the 3′ ends of the growing DNA strands.

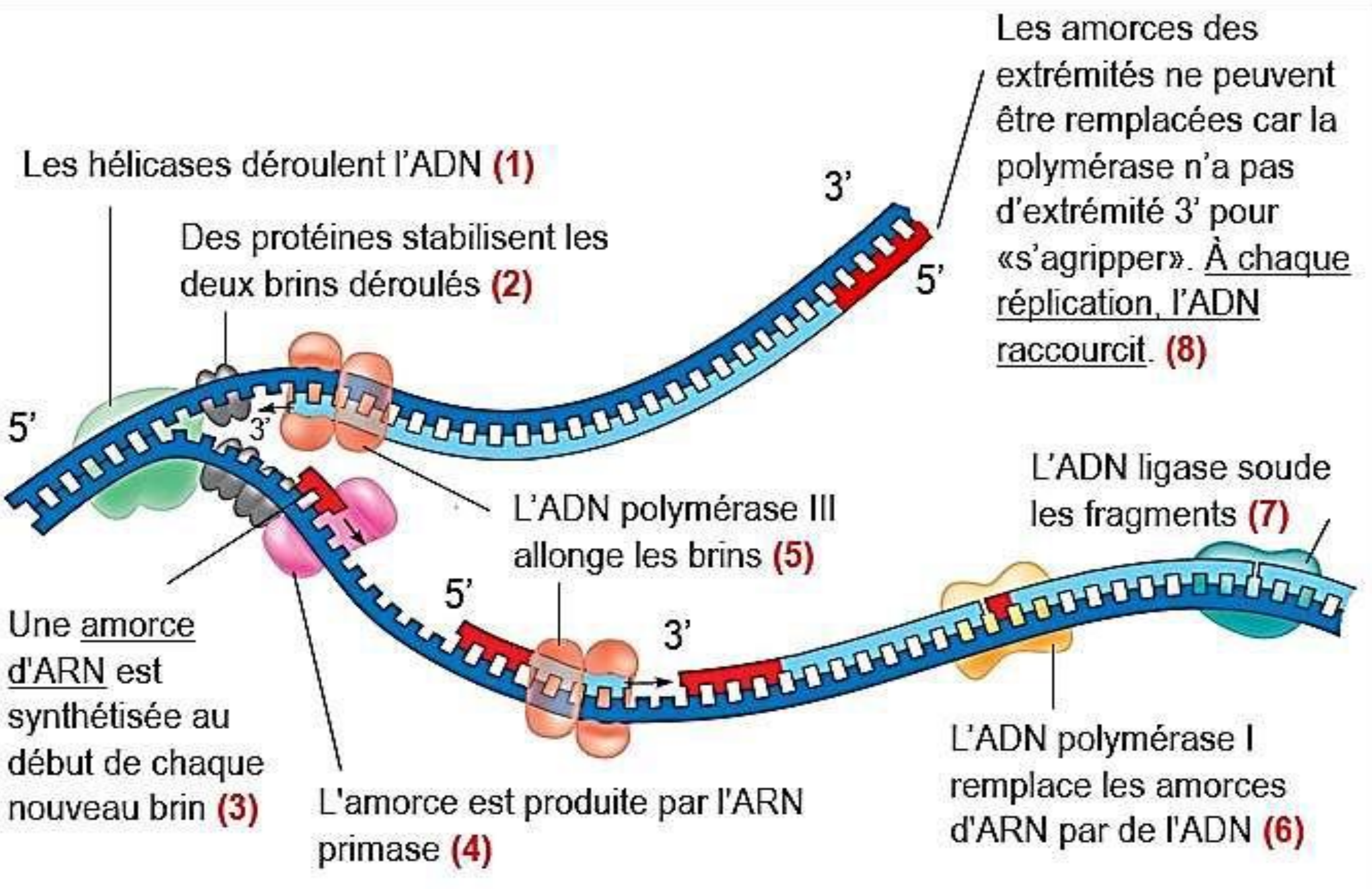
- Replication always proceeds in the 5′ → 3′ direction. Incoming nucleotides pair with the template strand bases via hydrogen bonds, following complementarity rules (A–T and G–C) in an antiparallel manner.

- The process is catalyzed by DNA polymerases, which require: the four deoxyribonucleoside triphosphates (dATP, dGTP, dTTP, dCTP), $Mg^{2+}$ ions, and the DNA template.

 In prokaryotes, there are three main DNA polymerases (I, II, and III). In eukaryotes, five main DNA polymerases function in replication (α, β, δ, ε, and γ).

- DNA polymerase extends the new strand by adding deoxyribonucleotides to the free 3′-OH of a primer. Each addition releases a pyrophosphate, and the energy released drives the formation of phosphodiester bonds between nucleotides.

- On the lagging strand, short fragments are synthesized discontinuously: primase synthesizes RNA primers, DNA polymerase III extends them, RNA primers are then removed, and DNA polymerase I fills the gaps. Finally, DNA ligase seals the nicks by joining the Okazaki fragments.



Campbell (3ᵉéd.) — Figure 16.16 : 331

*les étapes de la réplication*

| Étape | Description |
|---|---|
| **1. Initiation** | Formation d'une origine de réplication avec des protéines qui reconnaissent et se lient à la séquence d'ADN. |
| **2. Déroulement** | Déroulement de la double hélice par une enzyme appelée hélicase, formant ainsi des fourches de réplication. |
| **3. Synthèse des amorces** | Synthèse de courtes amorces d'ARN par une enzyme appelée primase. Ces amorces permettent le démarrage de la synthèse d'ADN. |
| **4. Synthèse des brins en continu et en discontinu** | Synthèse du brin continu (brin avancé) dans la direction 5' vers 3' par ADN polymérase. Synthèse du brin discontinu (brin retardé) sous forme d'Okazaki. |
| **5. Élongation** | Ajout de nucléotides complémentaires à chaque brin en utilisant l'ADN polymérase. |
| **6. Liaison des fragments** | Liaison des fragments d'Okazaki par une enzyme appelée ligase. |
| **7. Vérification et correction** | L'ADN polymérase vérifie l'exactitude de la nouvelle séquence d'ADN et effectue des corrections au besoin. |
| **8. Terminaison** | Arrêt de la réplication une fois que l'ensemble du génome a été copié. |