

CHAPTER 5

GENETICS &

EVOLUTION

At the end of this topic, students should be able to:

- ✓ Explain fundamental genetic concepts.
- ✓ Describe the structure and replication of the genetic material
- ✓ Describe basic concepts of transcription and translation
- ✓ Describe the phases of mitosis and meiotic in detail
- ✓ Understand the principles of Mendelian inheritance and their extensions
- ✓ Understand the principle of blood grouping and

Chapter 5: Genetics & Evolution

- ❖ Genetics is a field of biology that studies how traits are passed from parents to their offspring which is called **Heredity**
 - ✓ Therefore, genetics is the study of **Heredity**
- ❖ The basic components of genetics are DNA, RNA, genes, chromosomes and genetic inheritance
- ❖ DNA molecules hold all the genetic information for almost all organisms except RNA virus
- ❖ A **gene** is one particular section of a DNA molecule that tells a cell to perform one specific task (that **encode a single protein**)
- ❖ **Heredity** is what makes **offspring look like** their parents

5.1. Basic Principles of Mendelian genetics & patterns of inheritance (Gregor Mendel is father of **Genetics**)

- ❖ Gregor Mendel explained (**Pea** plant breeding)
 - ✓ How **traits** are passed from one generation to the next? &
 - ✓ How sometimes **skip generations occur**?
- ❖ After experimenting on pea plant breeding, developed **3** principles of inheritance (described the transmission of genetic traits)
 - 1.The Law/principles of Dominance (Uniformity)
 - 2.The Law/principles of Segregation of genes
 - 3.The Law/principles of Independent Assortment

Five Mendel's conclusions for the establishment of his rules

1. Characters are **unitary**, they are **discrete** (purple vs. white, tall vs. dwarf)
2. Genetic characteristics have **alternate forms**, each inherited from one of two parents, which is called **alleles**.
3. One allele is **dominant** over the other. The **phenotype** reflects the dominant allele.
4. Gametes are created by **random segregation**. Heterozygotic individuals produce gametes with an equal frequency of the two alleles
5. Different traits have **independent assortment**. In modern terms, genes are unlinked

5.2 Molecular Genetics and Inheritance

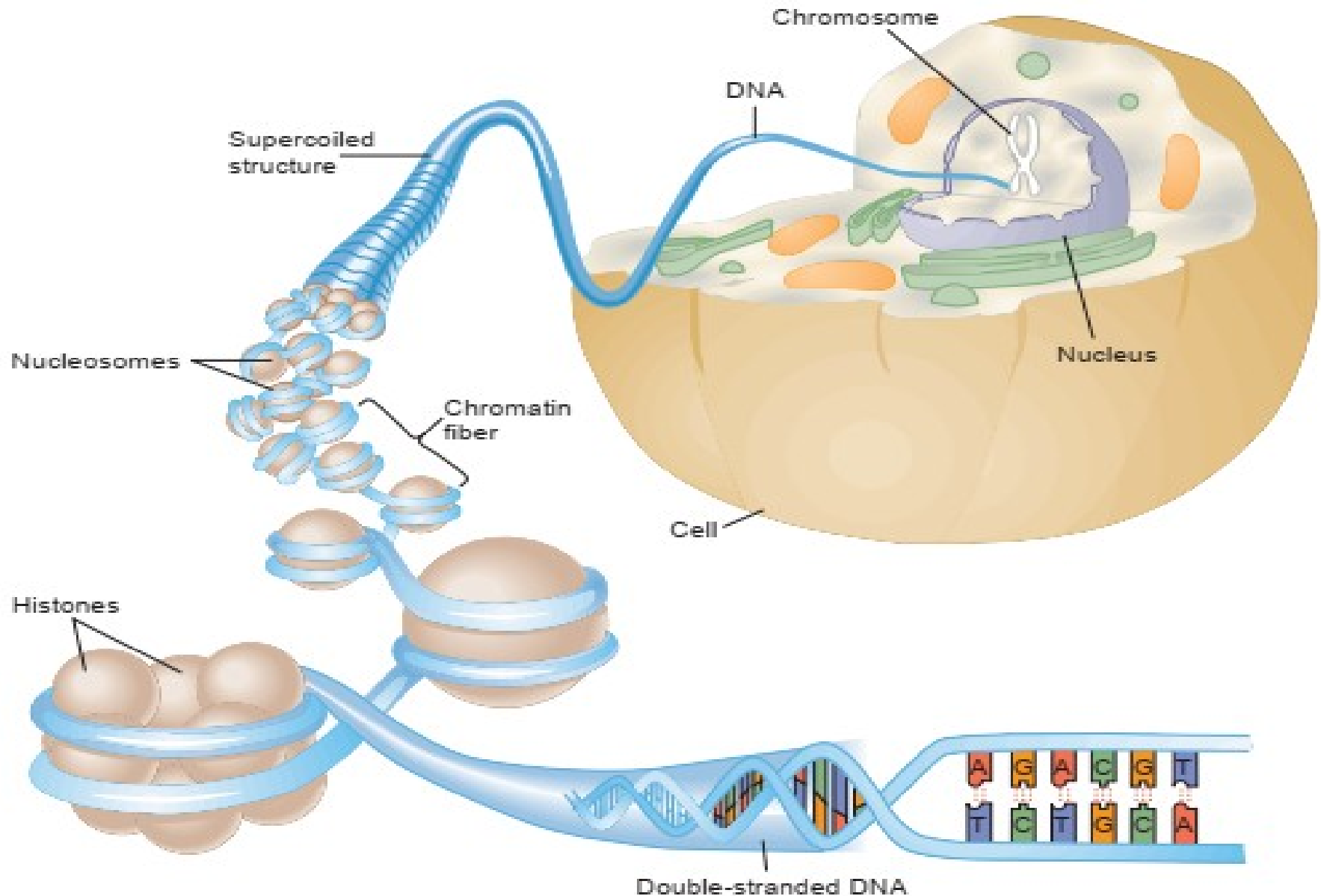
5.2.1. DNA, Gene, Chromosomes and Cell division

- ✓ **DNA** stands for **d**eoxyribo**n**ucleic **a**cid and double helix.
- ✓ DNA molecule contains a **code** that can be used by a cell to express certain genes
- ✓ Specific sections of a DNA molecule provide the information to build specific proteins which is expression of certain gene.
- ✓ DNA comes in the form of a long, linear molecule called **Strand**
- ✓ DNA molecules are replicated during cell division

Structure of DNA and chromosome

- Chromosome is a thread-like structure that is made up of **DNA** and **histone** (a set of globular 3⁰ proteins)
- While DNA is the molecule that **stores genetic information**
- Histone** is the core of a chromosome around which chromosome's DNA wrapped
- The loosely organized form of chromosome throughout the nucleus in loops when the cell is not dividing is called **Chromatin**

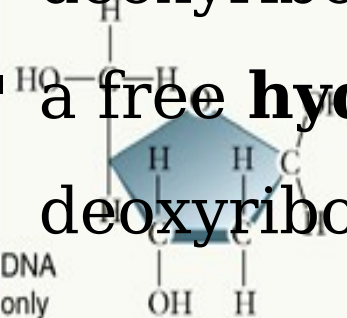
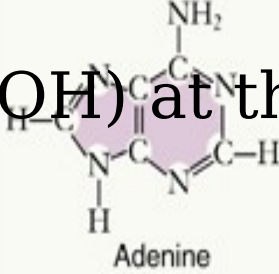
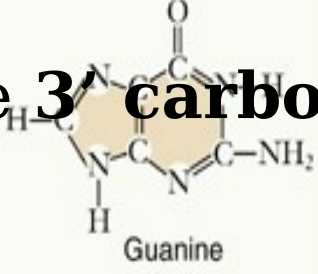
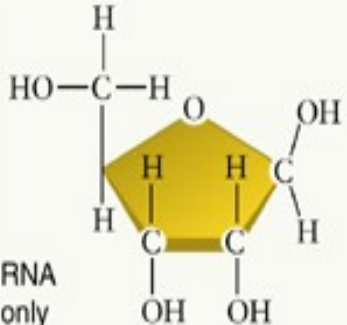
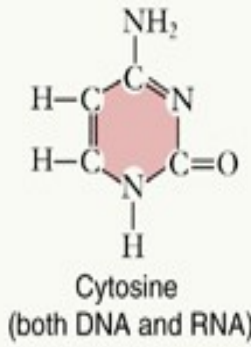
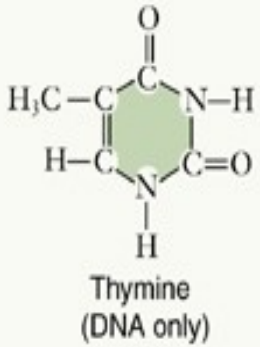
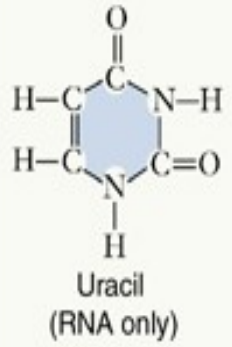
Structure DNA & chromosome



DNA Structure

The nucleotide structure consists of

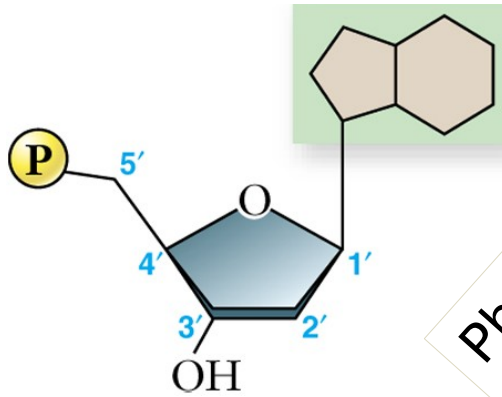
- The **nitrogenous** base attached to the **1' carbon** of deoxyribose
- The **phosphate** group attached to the **5' carbon** of deoxyribose
- a free **hydroxyl** group (-OH) at the **3' carbon** of deoxyribose

	Five-carbon Sugar	Phosphate Group	Nitrogenous Base		
Deoxyribose	 <p>DNA only</p>		 <p>Adenine</p>	 <p>Guanine</p>	
Ribose	 <p>RNA only</p>		 <p>Cytosine (both DNA and RNA)</p>	 <p>Thymine (DNA only)</p>	 <p>Uracil (RNA only)</p>

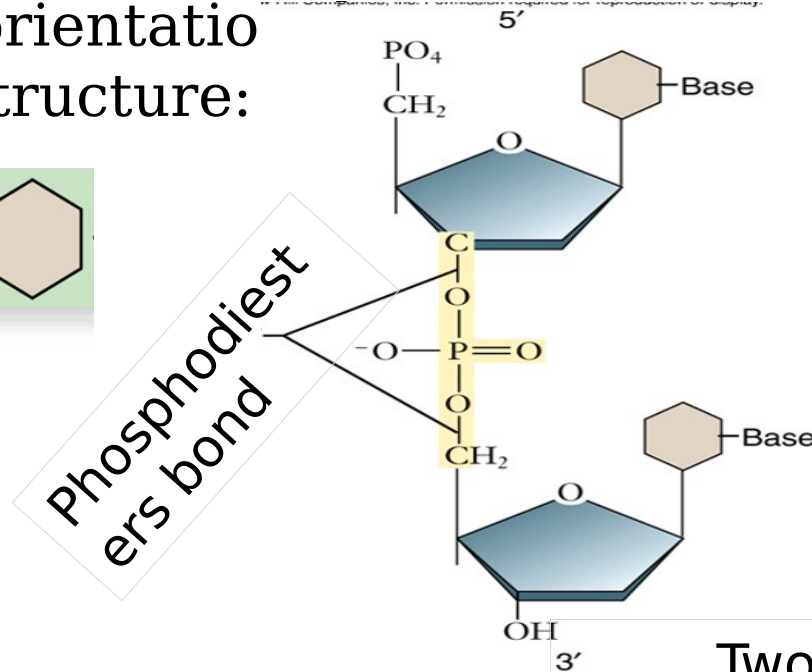
DNA Structure

❖ DNA consists of two strands

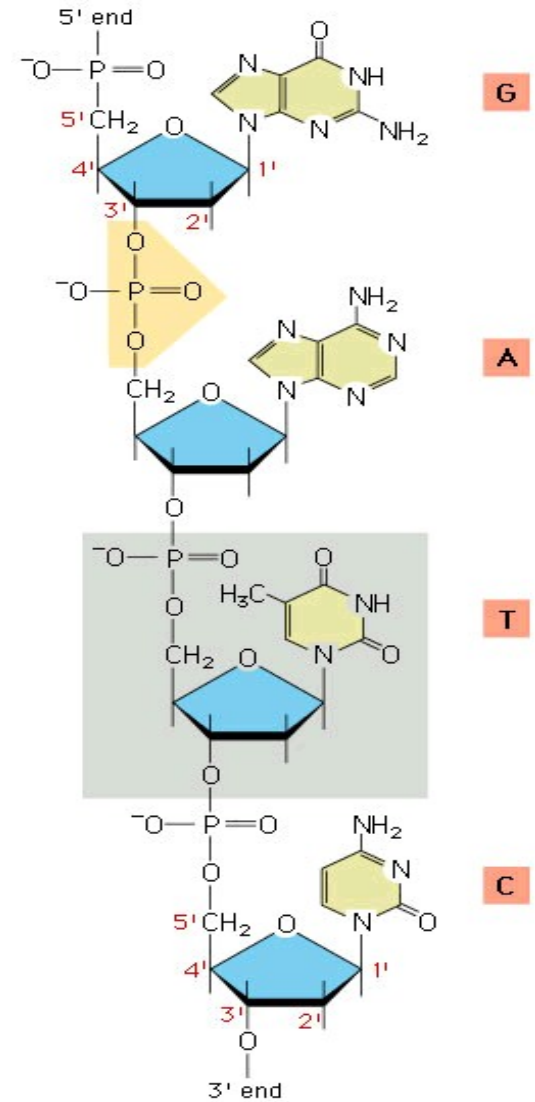
- ✓ The basic unit of DNA strand is a **nucleotide** (monomers of DNA)
 - ✓ Each strand is a **polymer** of nucleotides
 - ✓ DNA molecule has “**direction**”
 - ✓ Strand has orientatio
- nucleotide structure:



One Nucleotide



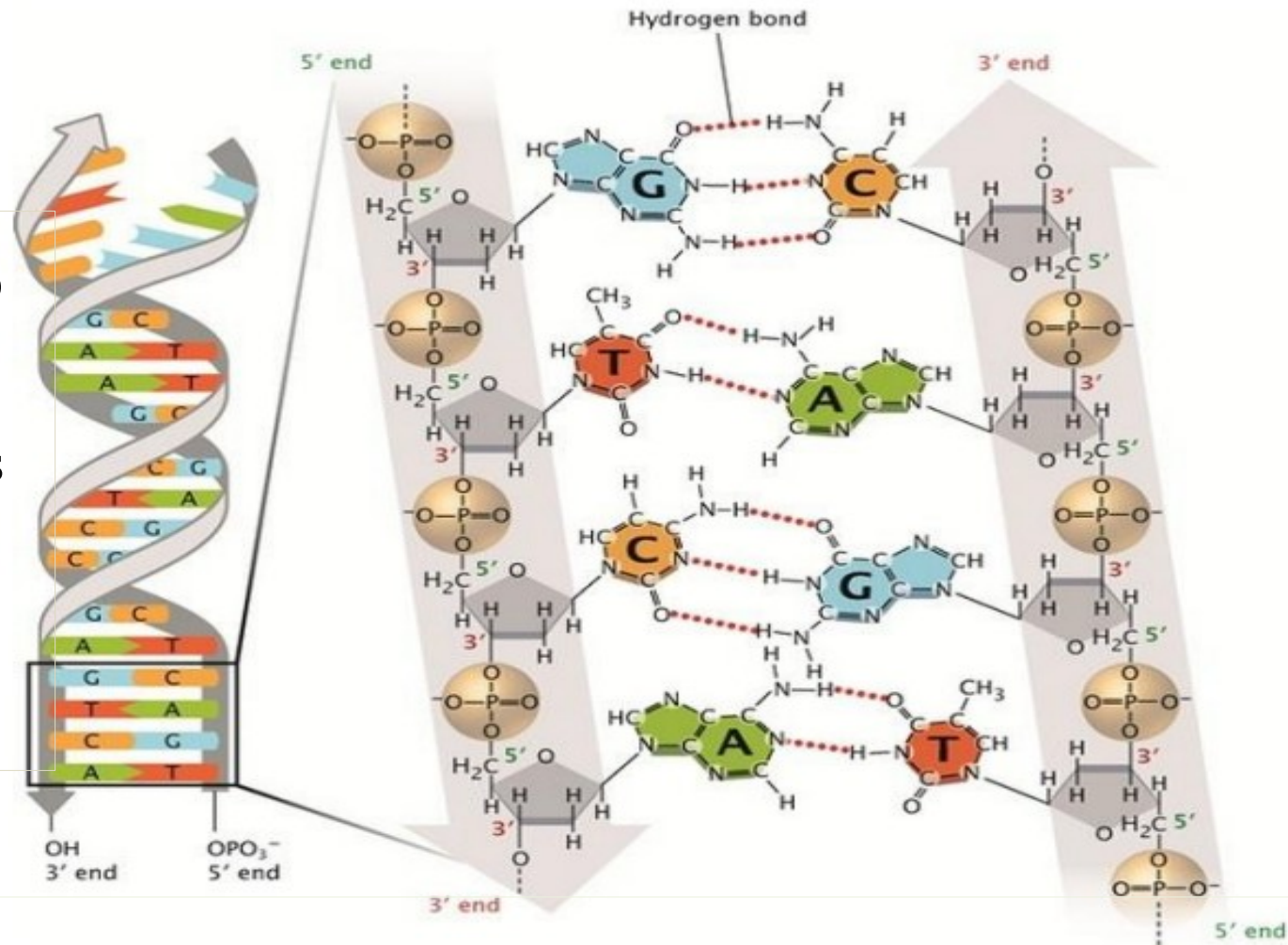
Two Nucleotides



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Polynucleotides

- DNA is made up of two strands of poly-nucleotides joined together & twisted into a double helix.

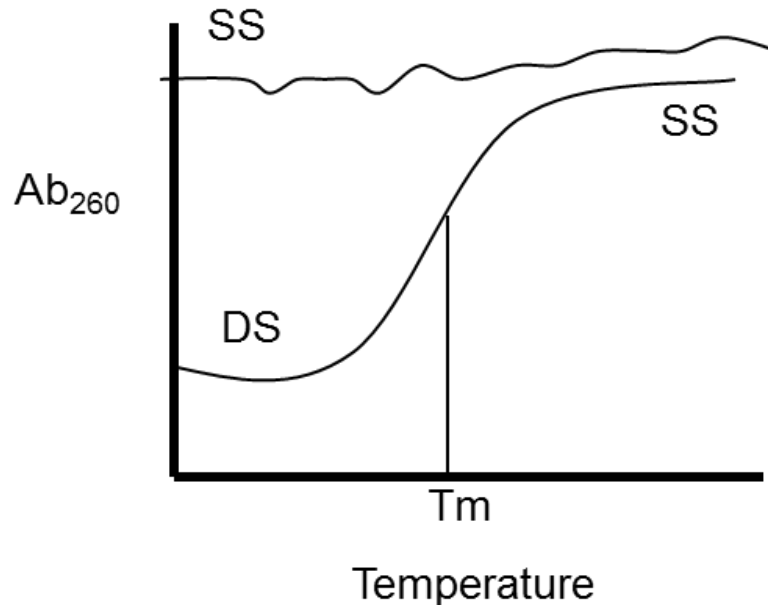


The double helix consists of:

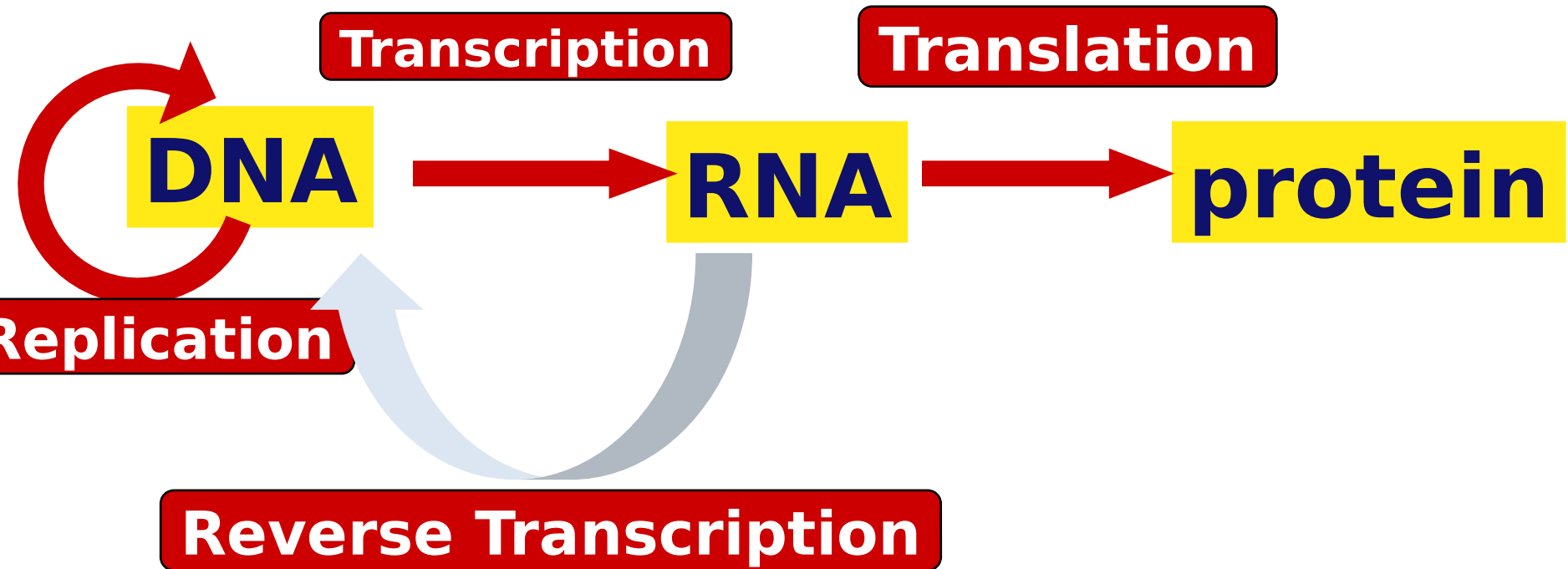
- **Nitrogenous bases** toward the interior of the molecule bases form **hydrogen** bonds with complementary bases on the opposite **sugar-phosphate backbone**
- The 2 strands are **antiparallel**

Denaturing and Annealing of DNA

- DNA is a very stable molecule at normal temperature
- The hydrogen bonds hold the two strands together in position through the bases
- **T_m (*melting temp.*):** temperature at which 50% of DS DNA denatured to SS



Flow of genetic information in a cell



The “Central Dogma”

DNA replication and cell division

- ✓ The ability of DNA to make copy of itself (DNA-replication) is the basis for reproduction and inheritance.
- ✓ DNA structure is double helix & must replicate **semi-conservatively**.
 - Each formed new DNA molecule contains one strand from the original (old) DNA and one new strand DNA molecules.
 - Both new DNA molecules formed are identical to each other and to the original molecule.

DNA replication

Unwinding and opening DNA

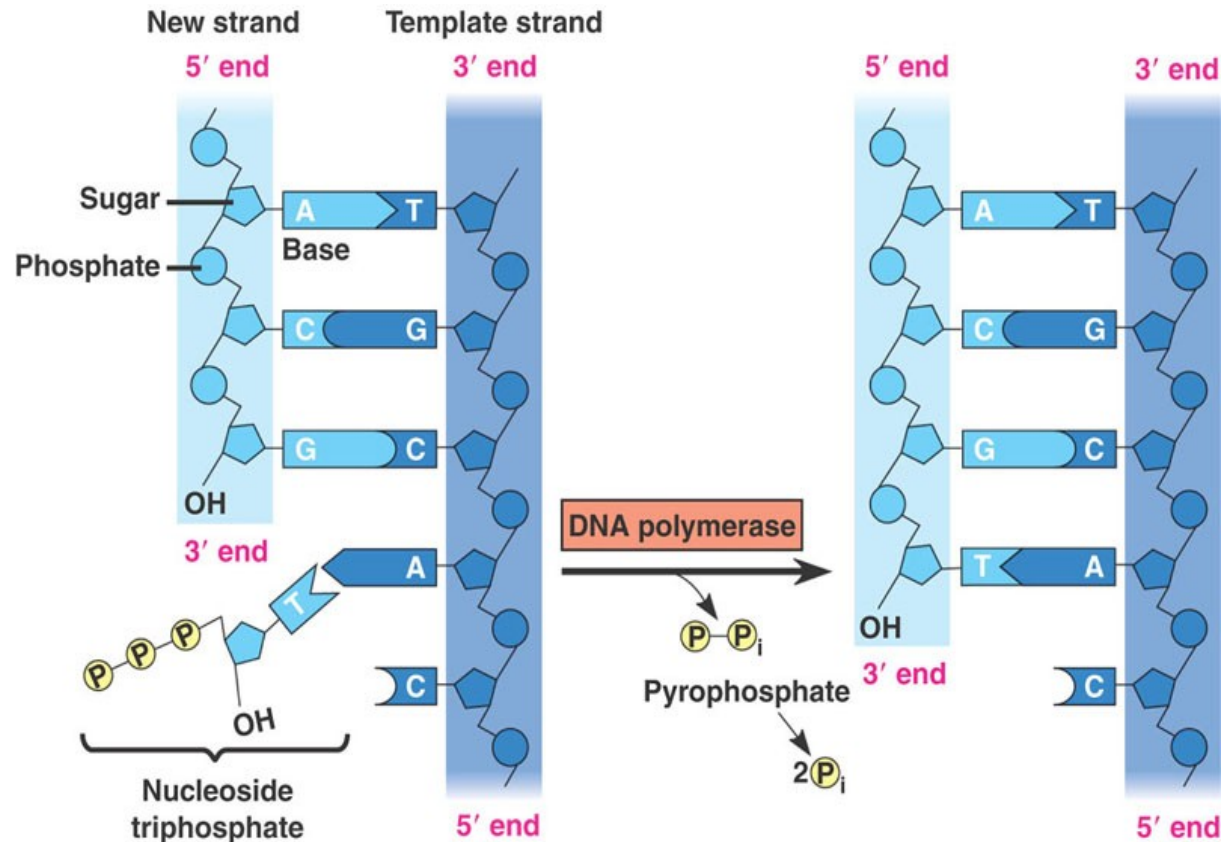
- The twisted double helix must be unwound and the base pair bonds broken (“opening” the DNA molecule)
- **DNA helicase** does the unwinding and opening
- **Single-strand DNA binding proteins** keep it open
- **Topoisomerases** break and rejoin strands, resolving knots and strains that occur

DNA replication

Direction of synthesis

- **DNA polymerases** direct synthesis of new strands synthesis proceeds by adding nucleotides onto the 3' end of a strand
- thus, synthesis can only proceed in the **5' → 3'** direction

- The nucleotide added is from a deoxynucleotide triphosphate; two phosphates are released in the process - energy to drive the reaction comes from these



DNA replication

Priming new strands

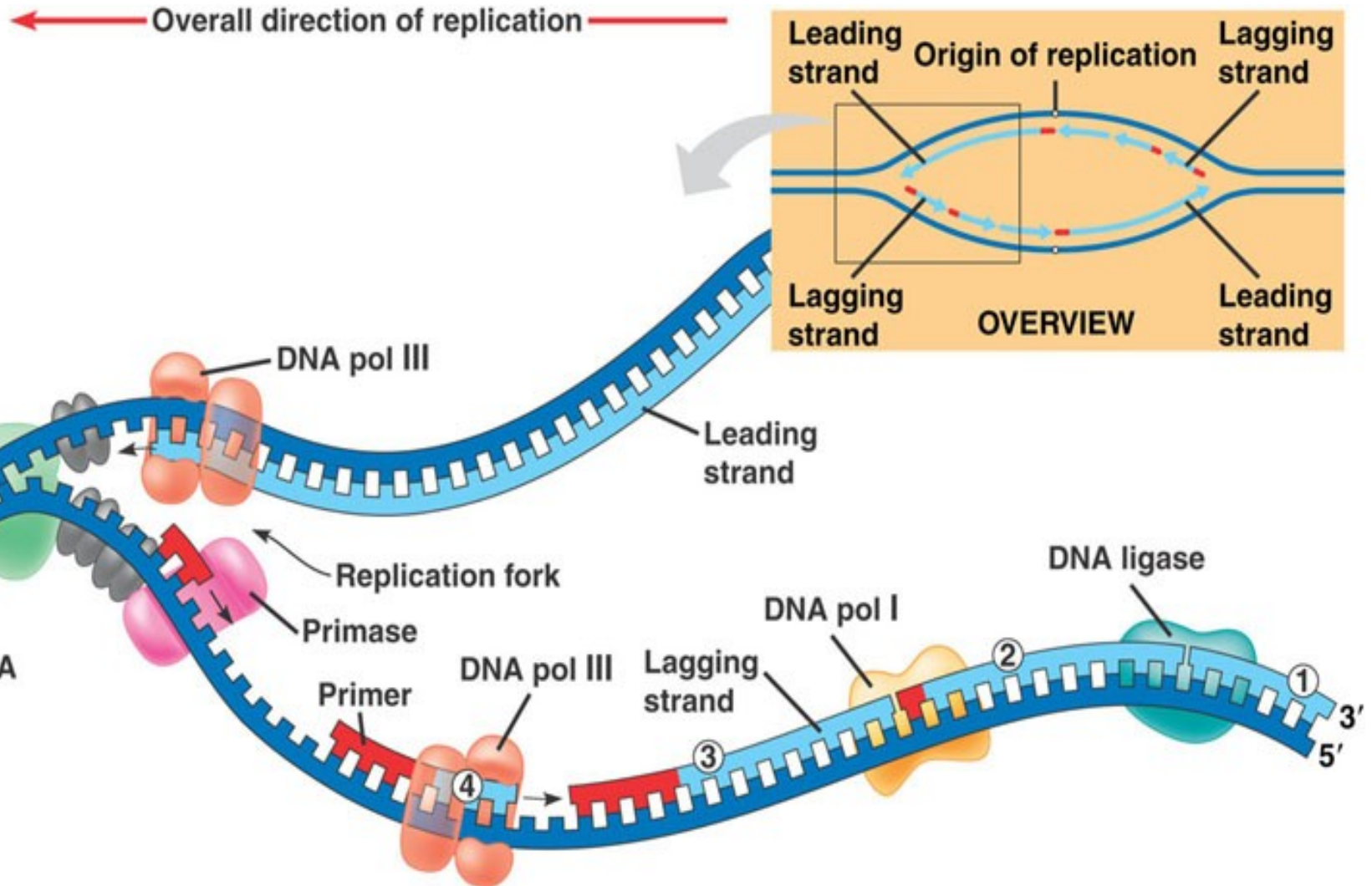
- DNA polymerase can only add onto an existing strand, so it can't start the strand
- **Primase** starts the strand by making an **RNA primer** that is a few (usually ~ 10) ribonucleotides long
- DNA polymerase can then add nucleotides starting at the end of the RNA primer
- the RNA primer is later degraded and (usually) replaced with DNA

DNA replication

Leading and **lagging** strands

- The 5' → 3' directionality of synthesis complicates the replication activity
- One strand being synthesized, the **leading strand**, has its 3' end at the fork; thus, its synthesis can proceed continuously, in the direction that the fork moves
- The other, lagging strand has its 5' end at the fork; it must be synthesized in the “opposite direction” from the leading strand
 - The lagging strand is thus made in short (100-1000 nt) **Okazaki fragments**
 - Fragments are later connected by **DNA ligase**

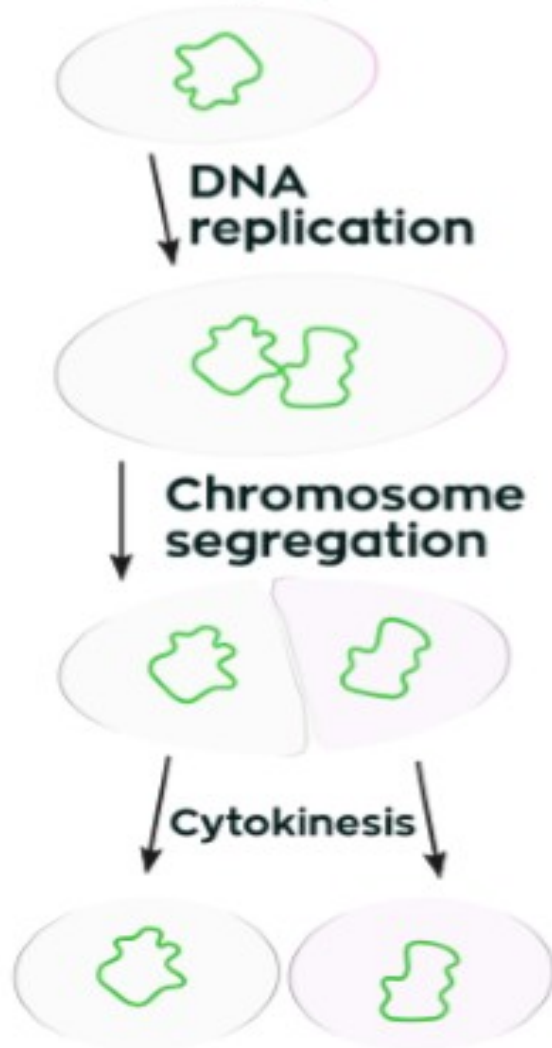
DNA Replication



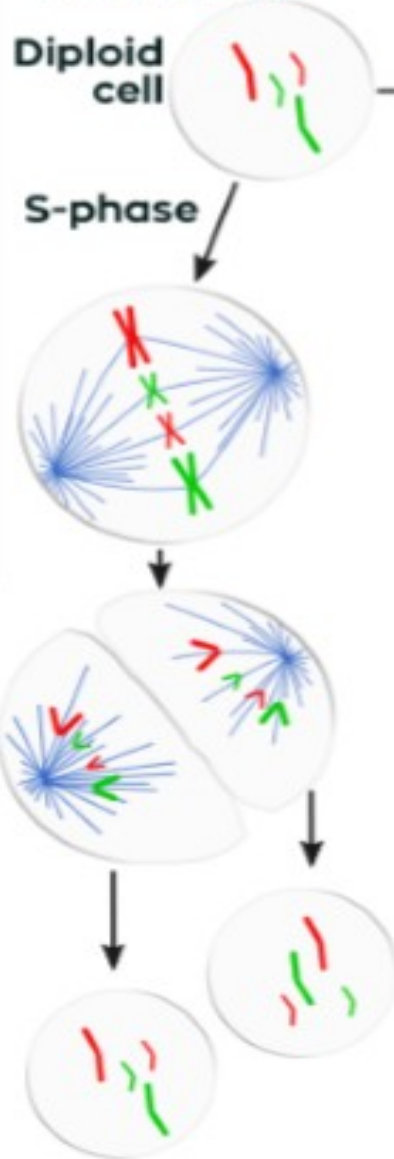
Cell division

- Cell division is the process by which a parent cell divides into two or more daughter cells.
- In eukaryotes, there are two distinct types of cell division:
 - I. Mitosis:** one cell divides into two identical daughter cells
 - II. Meiosis:** results in four haploid daughter cells by undergoing one round of DNA replication followed by two divisions
- Homologous chromosomes are separated in the first division
- Sister chromatids are separated in the second division

Binary fission



Mitosis



Meiosis

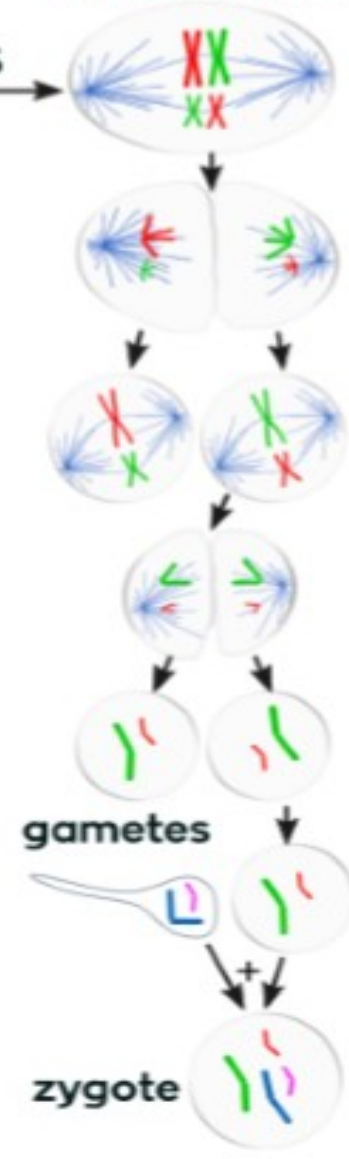


Fig: 5.3. Major types of cell division

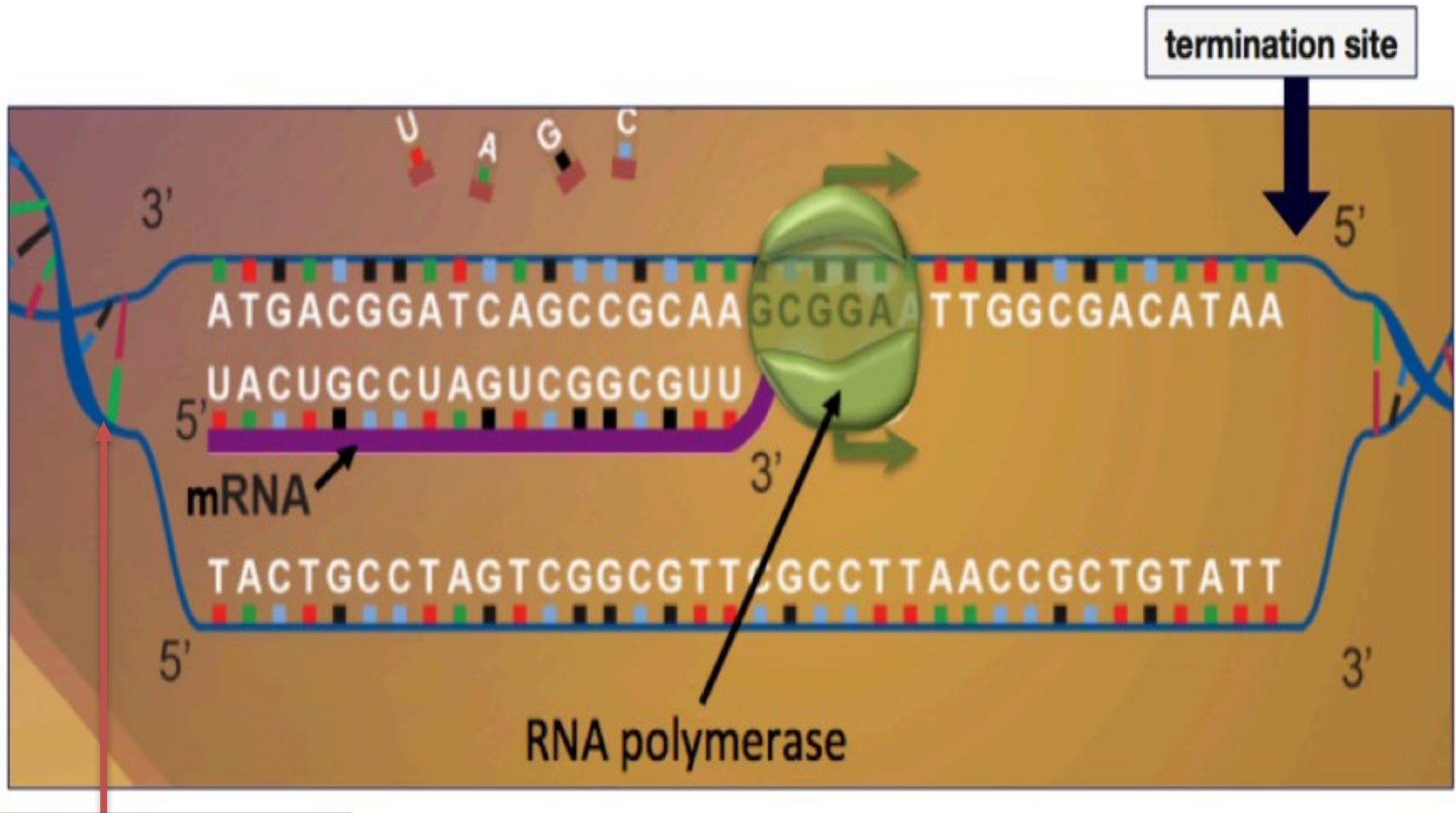
Mechanisms of Transcription

- ❖ Information must be transcribed from DNA in order function further

Transcription:

- ❖ The synthesis of RNA molecules using DNA strands as the templates so that the genetic information can be transferred from DNA to RNA.
- ❖ This RNA copy is called **messenger RNA (mRNA)**
- ❖ **It requires:** RNA polymerase, four NTP , Mg^{2+} or Mn^{2+} , and DNA template
- ❖ ***Promoter sites*** are specific sequences of nucleotides at the beginning of a gene.

Mechanisms of Transcription



Promoter
site

5.3 Protein synthesis

- Code for protein synthesis is specified by DNA and has to be sent to ribosome.
- DNA is a huge molecule and remains in nucleus to assemble amino acids in the correct sequence to form protein.
- Events during protein synthesis
 - i. mRNA travels from nucleus to ribosome
 - ii. Free amino acids are transported from cytoplasm to ribosome by transfer RNA (tRNA) molecules
 - iii. Ribosome read mRNA code and assembles amino acids presented by tRNA into a protein by a process called translation

❖ Hence, a gene is a sequence of base triplets in the DNA molecule that carries a code for a protein.

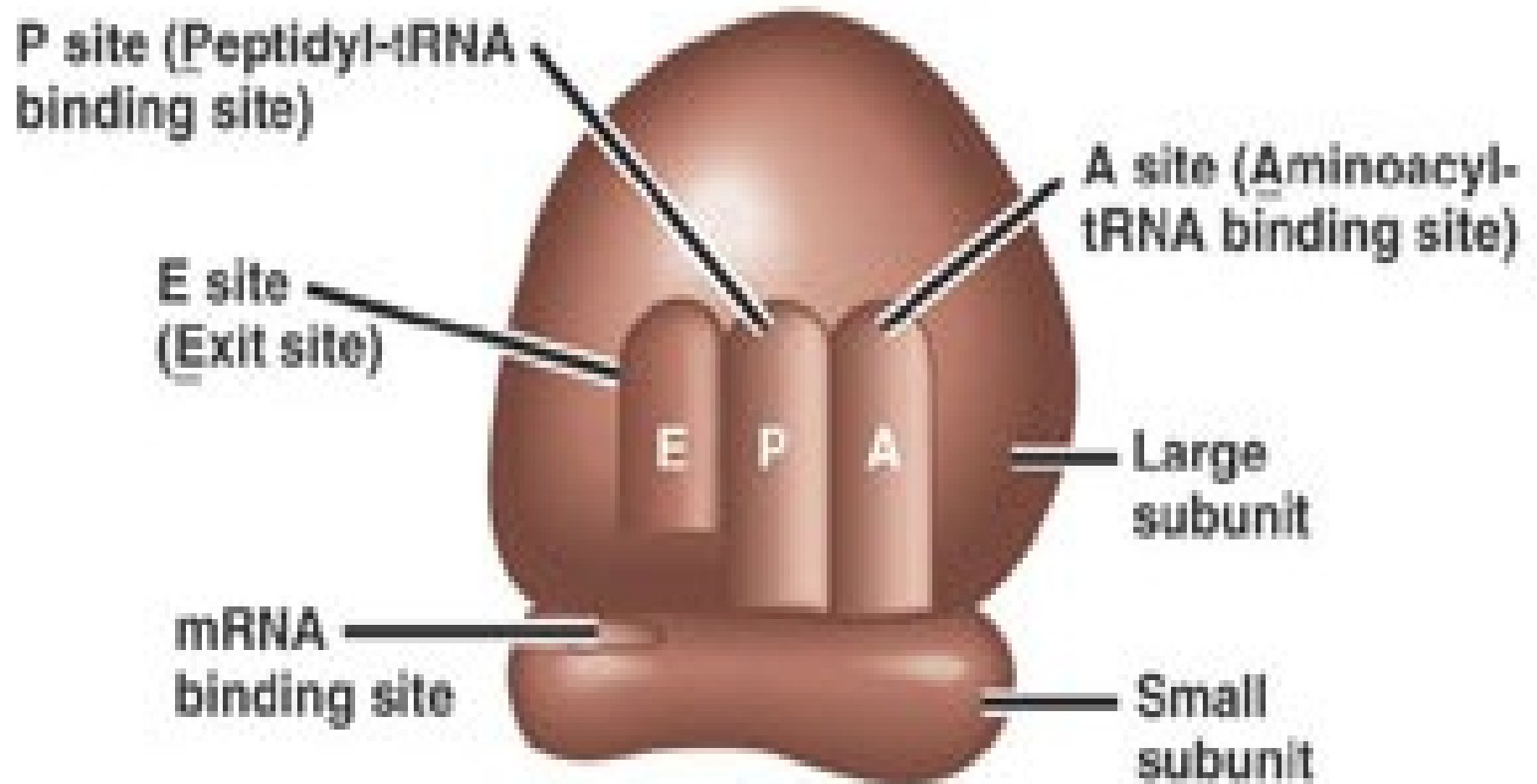
1.Codons are triplet : Each group of 3 nucleotides on the mRNA is a codon. Since there are 4 bases, there are $4^3 = 64$ possible codons, which must code for 20 different amino acids

2. It is co-linear. The sequence of amino acids in the polypeptide, from amino end to carboxyl end, corresponds exactly to the sequence of their

- 3. It is non-overlapping and “commaless.”** The codons are aligned without overlap and without empty spaces between them. Each base belongs to one and only one codon.
4. It contains 61 amino acid coding codons and the three stop codons UAA, UAG, and UGA. One of the amino acid coding codons, AUG, is also used as a start codon.
- 5. It is unambiguous.** Each codon specifies one & only one amino acid
- 6. It is degenerate.** More than one codon can code for an amino acid

The ribosome for protein synthesis

- ❖ The large subunit has depressions where tRNAs can fit
- ✓ The **E site** is where uncharged tRNA molecules are moved and then released
- ✓ The **P site** is where the completed part of the polypeptide chain will be attached to tRNA
- ✓ The **A site** is where the new amino acid



Schematic model showing binding sites

The ribosome for protein synthesis ...

An Overview of Translation.

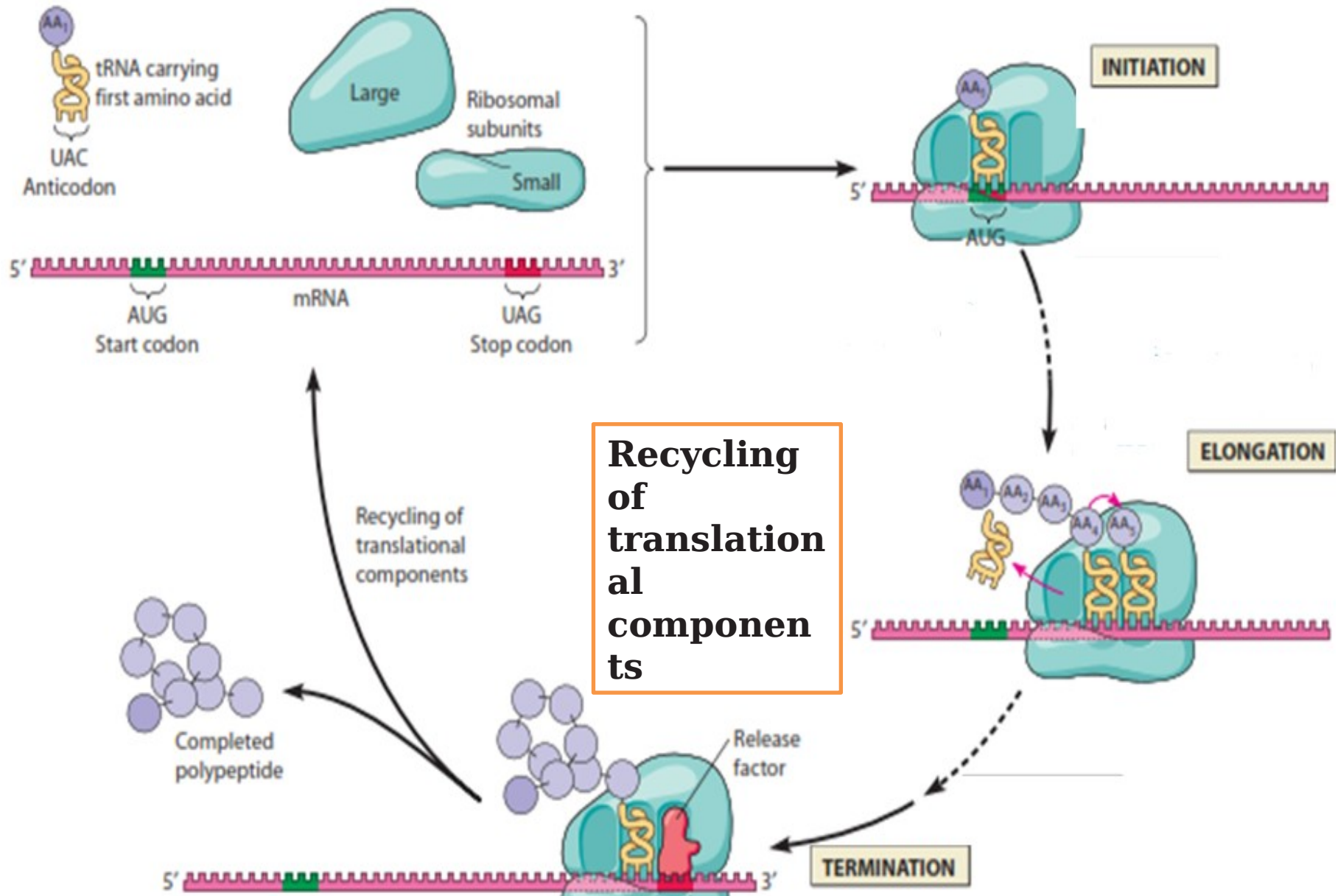
❖ **Translation** occurs in 3 stages: initiation, elongation, & termination

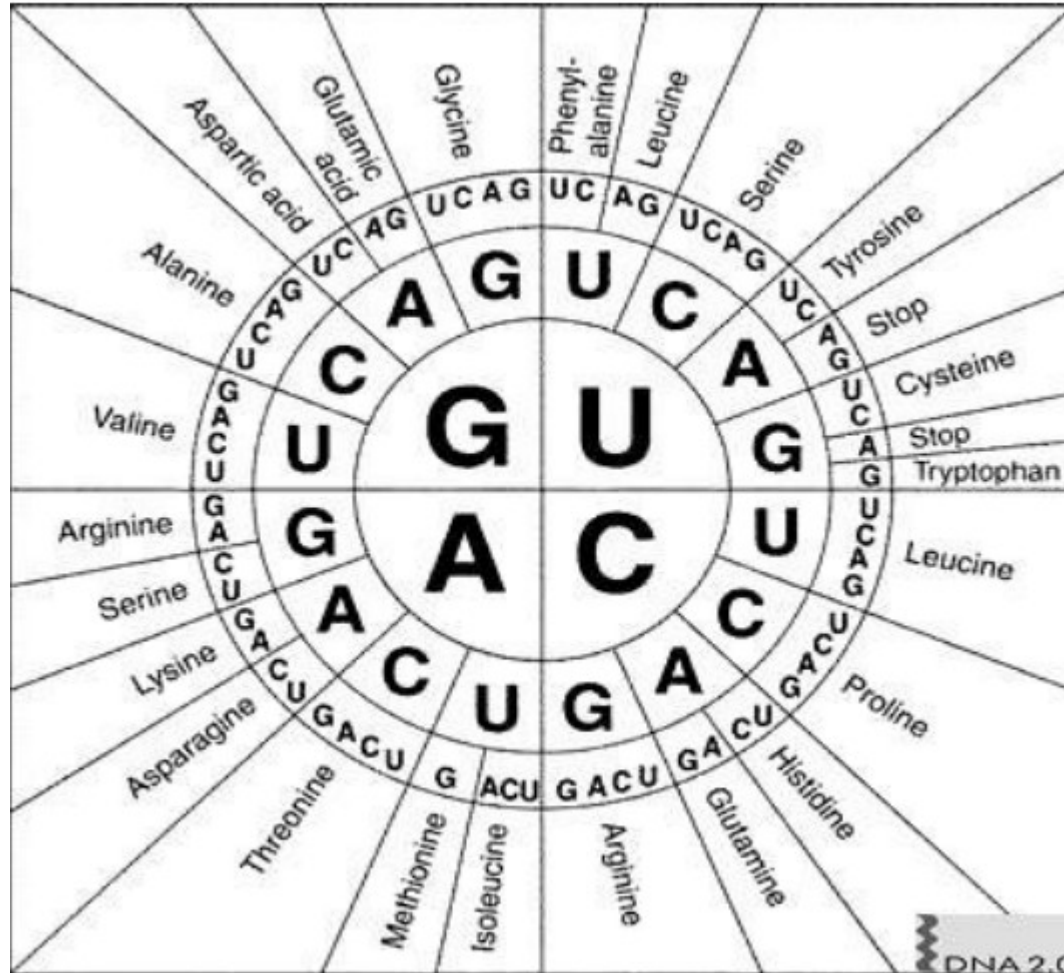
1During initiation: the components of the translational apparatus come together with mRNA, & a tRNA carrying the first amino acid (AA) binds to the start codon (AUG).

2During elongation: amino acids are brought to the mRNA by tRNAs and are added, one by one, to a growing polypeptide chain

3During termination: a stop codon in the mRNA is

Ingredients





Regulation of Gene expression

👉 Gene expression is regulated at multiple levels.

👉 It includes

1. *DNA*

2. *At initiation*

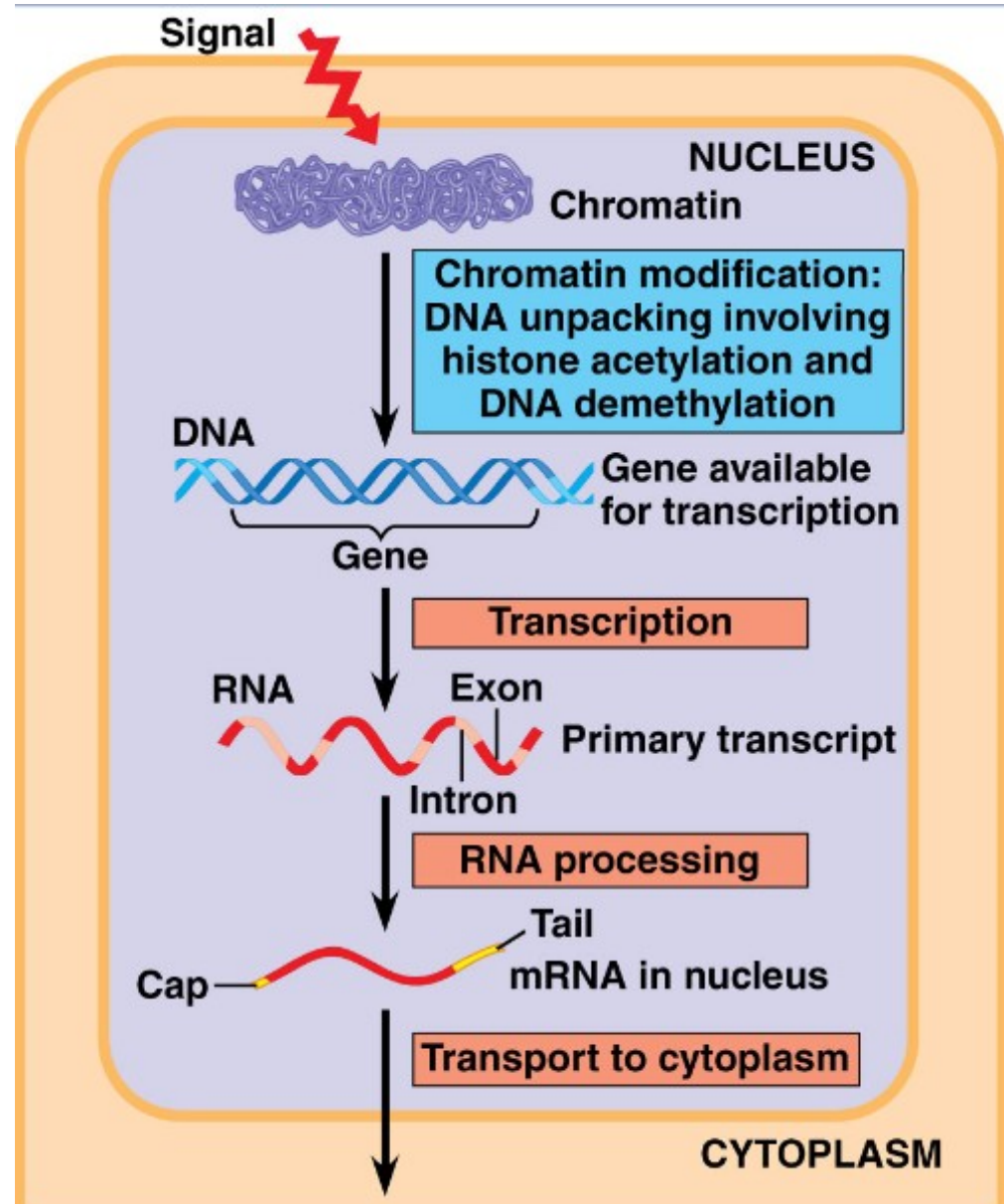
Transcriptional

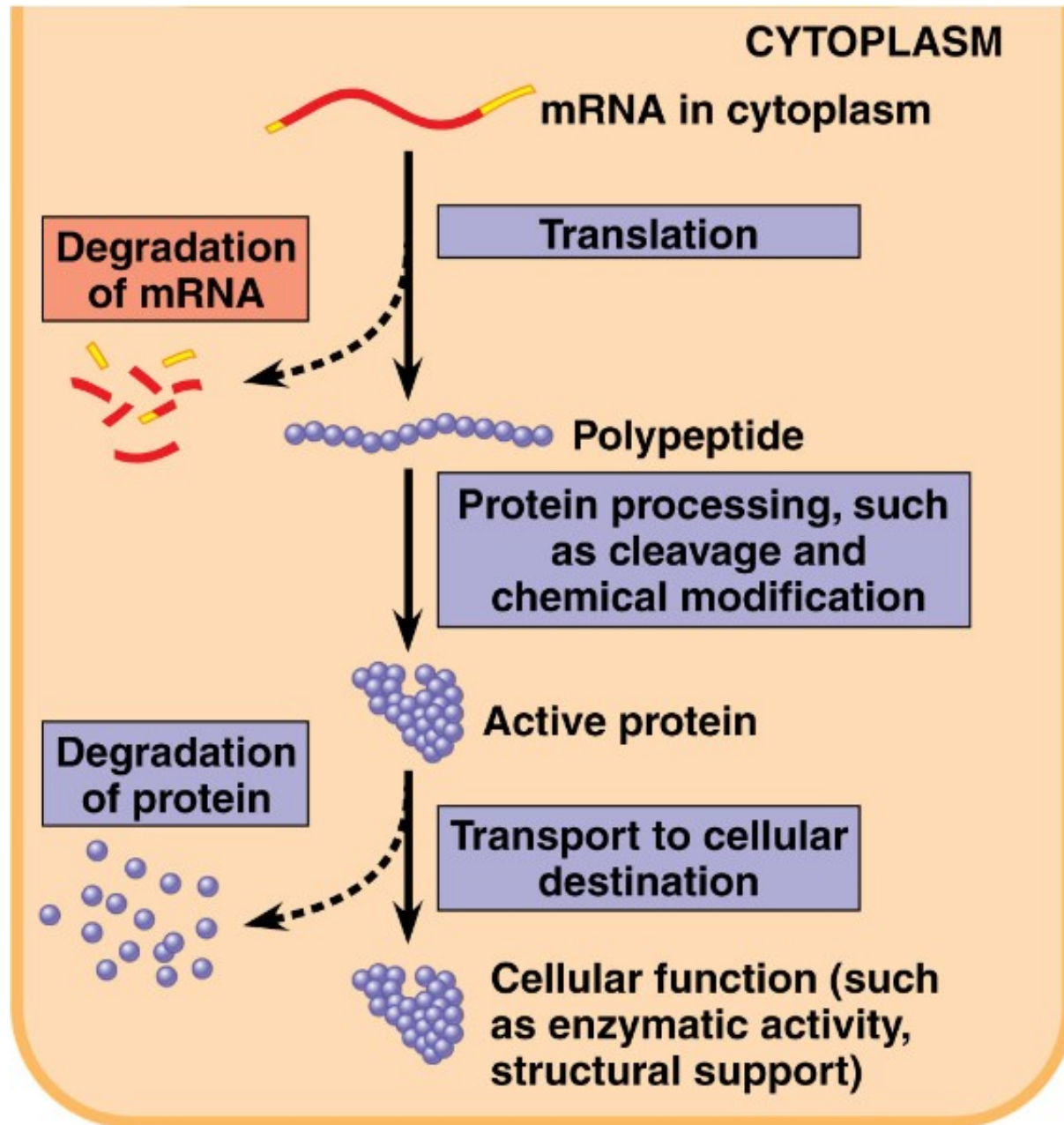
3. *During transcription*

4. *Post-transcription,*

5. *Translational control*

6. *Post-translational*





Mutations

- ✓ Mutation is the alteration of the nucleotide sequence of the genome of an organism, virus, or extra-chromosomal DNA.

1. Point mutations- changes that involves a single base.

There are several types of point mutations:

- ✓ Substitution - one base is replaced by other base
- ✓ Addition - an extra base is added.
- ✓ Deletions - a base is missed out during DNA replication.

2. Chromosomal Mutations: situation where part /segment/ of a chromosome sequence of DNA is disturbed/ a chromosome is missed/added.

- ✓ Types of chromosomal mutations: **Euploidy/polyploidy/ & Aneuploidy**

Mutations ...

- **Euploidy/polyploidy** - is a condition where an organism/a cell has one complete set of extra chromosomes/an exact multiple of a complete set. E.g., Triploid, Tetraploid
- **Aneuploidy** - is a condition where an organism/a cell lost from or added to one or more chromosomes to/the normal set of chromosome
 - ✓ $2n+1$ = trisomy/47 chromosomes, e.g. Down's syndrome
 - ✓ $2n-1$ = monosomics - turner syndrome/45chr.
 - ✓ $2n+1+1$ = double trisomy
 - ✓ $2n-2$ - nullisomic, organisms that loss one homologous chromosome

Manipulation of DNA: Genetic engineering

- Genetic engineering is a process by which the genome of an organism is altered, usually by having extra (foreign) gene from different organisms, and the organism is termed genetically modified organism (GMO), transgenic organism or genetically engineered organism.
- ❖ Genetic engineering is early done on Bacteria, to produce useful products like:
 - ✓ Insulin, antibiotics, washing enzyme
 - ✓ Enzyme for food processing industry
 - ✓ Human growth hormone
 - ✓ Vaccines-Hepatitis B
 - ✓ Bovine somatotrophin, high yield milk & muscle

GMO – Genetically Modified organism importance

Increasing agricultural yields –

- Insect resistant plants
- Disease resistance plants
- Herbicide resistance plants
- Getting genes from Nitrogen fixing bacteria inserted into plants
- Salt tolerant plants
- Specific products, golden rice, carotene VA

Moreover, animals are genetically modified for the following purposes

- high yield of protein, high growth rate
- Specific products eg. insulin,
- Detection of water pollution =glofish glow in the dark b/c they have had bioluminescent gene from jelly fish.

Manipulation of DNA: Genetic engineering

- ❖ A number of genes can be combined with crops to produce desirable properties such as:
 - Herbicide-, drought-, freeze- or disease-resistance
 - Higher yield ;
 - Tolerance towards cold, drought, salt , acid
 - Faster growth;
 - Improved nutrition: golden rice, carotene VA;
 - Delay of senescence;
 - Longer shelf life;
 - Increased post-harvest shelf life;
 - Altered flower pigmentation;
 - Nitrogen fixation Capacity to fix atmospheric nitrogen, and

Manipulation of DNA: Genetic engineering

The main applications of genetic engineering in medicine are

- Biopharmaceuticals and vaccines
- Hormones- insulin
- Production of blood clotting factors
- Monoclonal antibodies
- Gene therapy
- Tissue engineering

Some other potential applications of genetic engineering are:

- Disease could be prevented by detecting defected genes.
- To treat infectious diseases by implanting antiviral proteins (antibodies).
- To produce plants and animals that have high growth rate

ABO blood groups and Rh Factors

- ABO Blood Type: An individual's red blood cells will contain proteins of type A, or B, or both, or neither. The body produces antibodies that will attack any foreign type.

Genotype	Blood Type	Antigens	Antibodies	Donate To	Receive From
i i	Type O	None	Anti-A and Anti-B	A, B, AB, O	O
I _A I _A	Type A	A	Anti-B	A, AB	A, O
I _A i	Type A	A	Anti-B	A, AB	A, O
I _B I _B	Type B	B	Anti-A	B, AB	B, O
I _B i	Type B	B	Anti-A	B, AB	B, O
I _A I _B	Type AB	A and B	None	AB	A, B, AB, O

Rh Factor (D antigen): The Rh factor, the second most important blood group system after the ABO blood group system, was first discovered in Rhesus monkeys.

- The Rh factor is inherited independently from the ABO blood type.
- Genotypes for the Rh factor are $+/+$, $+/-$, and $-/-$.
- People who are $+/+$ or $+/-$ possess the Rh (D) antigen and test as Rh positive.

■ P₀ antigen

Genotype	Phenotype	Blood Proteins	Blood Antibodies	Donate To	Receive From
$+/+$	Rh ⁺	Rh(D) proteins	None	Rh ⁺	Rh ⁺ or Rh ⁻
$+/-$	Rh ⁺	Rh(D) proteins	None	Rh ⁺	Rh ⁺ or Rh ⁻
$-/-$	Rh ⁻	None	Anti-Rh(D)	Rh ⁺ or Rh ⁻	Rh ⁻

Rh Sensitization: One interesting medical scenario involves an Rh negative mother who carries an Rh positive baby.

- The baby of an Rh positive father and an Rh negative mother can be +/- or -/-.)
- If the baby is +/-, the first pregnancy causes Rh sensitization in the mother, because she is exposed to foreign proteins and builds up antibodies against them.
- Future pregnancies can be increasingly difficult, as the mother's antibodies attack the baby.