GENE EXPRESSION

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Molecular Biology

Semester I

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Learning Objectives

- Define gene expression and outline its biological significance
- Describe transcription, RNA processing, and translation in detail
- Explain major regulatory mechanisms
- Discuss epigenetic control
- Understand the role and types of RNA
- Identify methods used to analyze gene expression

Introduction to Gene Expression

- **Genes** are basic units of inheritance that contain the genetic information necessary to determine the specific traits in an organism.
- Genes contain the instructions for producing proteins that perform various functions to keep the cell alive and functioning.
- Protein plays specific roles in the cell, contributing to the structure, function, and regulation of various biological processes.

Introduction to Gene Expression

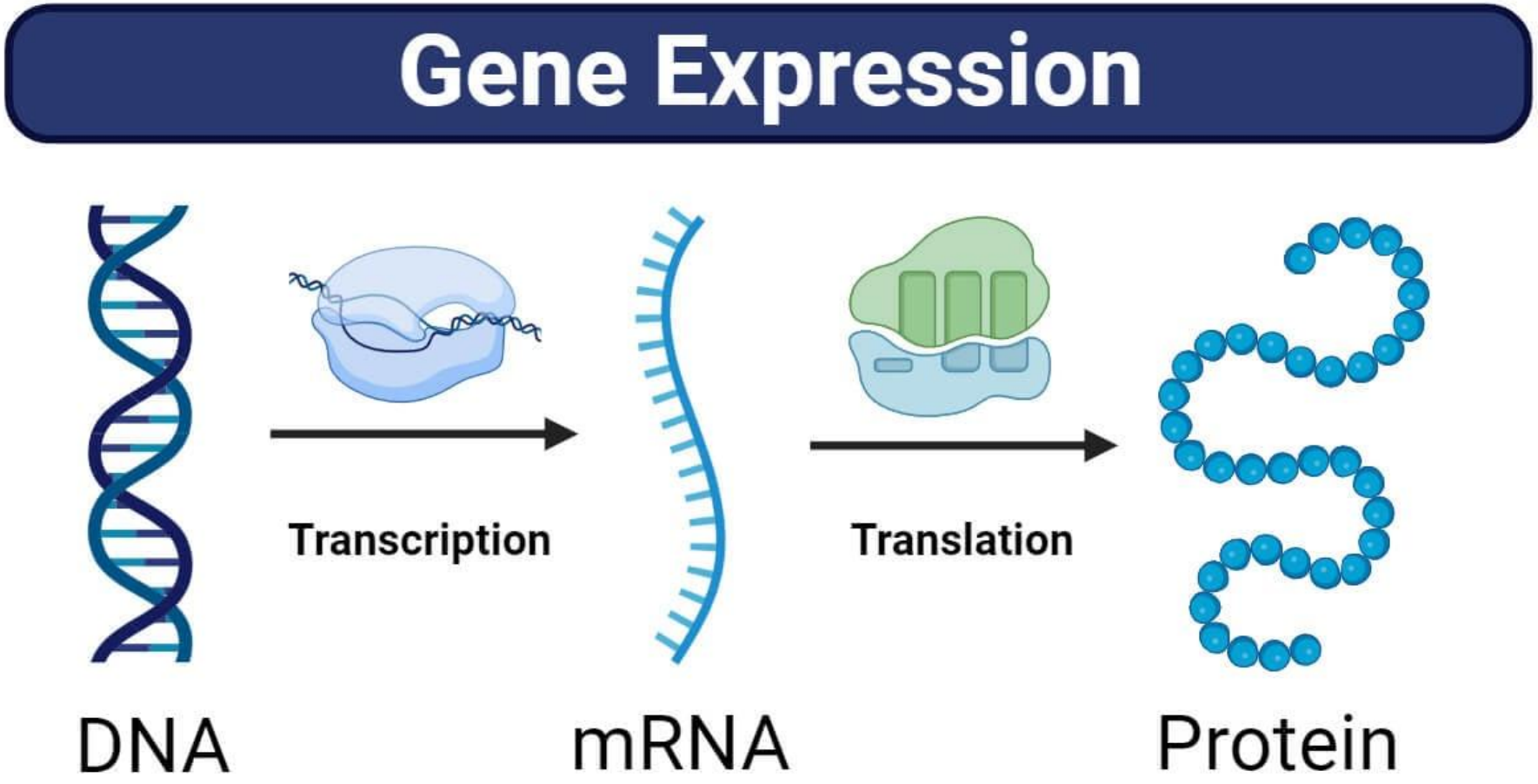
- This process of activation of genes to produce proteins is called **gene expression**. This activation leads to the creation of **messenger RNA (mRNA),** which acts as a template for building the proteins.

Gene expression is the **fundamental biological process** through which DNA instructions are converted into functional molecules that determine:

- cell shape
- cell function
- phenotype
- responses to environment

- Gene expression is a vital process in cells that ensures specific proteins are created at the right time and in the right quantities.

Introduction to Gene Expression



Introduction to Gene Expression

Protein production defines:

- cell structure (e.g., actin, tubulin)
- metabolism (enzymes)
- communication (cytokines, receptors)
- developmental identity (transcription factors)
- immune responses
- disease states

Introduction to Gene Expression

Only ~1–2% of human DNA encodes proteins, but **95% of the genome is actively transcribed**, producing:

- mRNAs
- regulatory RNAs
- structural RNAs
- catalytic RNAs

RNA: The Central Functional Molecule in Gene Expression

RNA is more than a messenger, and it is the functional interface between dynamic gene regulation and proteomic output.

Why RNA is indispensable:

Why RNA is indispensable:

- **DNA is stable and protected → not suitable for rapid changes**

  Cells must respond to:

  - extracellular signals
  - stress
  - nutrient availability
  - infection

Proteins may need to be produced **within minutes**.

RNA allows quick transcription, modulation, and degradation.

Why RNA is indispensable:

- **RNA is chemically flexible**
  - Can fold into secondary and tertiary structures.
  - Can bind proteins.
  - Can catalyze reactions (ribozymes).
  - Can guide epigenetic modifications.
- **RNA regulates genome architecture**

Certain RNAs recruit histone modifiers and DNA methylases to specific genomic regions.

Exhaustive Overview of RNA Types and Their Functions

RNA can be divided into:

A. Protein-Coding RNA

B. Non-Coding RNA (regulatory & structural)

A. Protein-Coding RNA

1. mRNA (Messenger RNA)

- Encodes amino acid sequence.
- Contains 5′ UTR, coding region, 3′ UTR.
- Modifications: 5′ cap, splicing, poly-A tail.
- Average half-life:
  - Bacteria: minutes
  - Mammals: hours to days

Regulatory elements:

- 3′ UTR → miRNA binding sites
- 5′ UTR → ribosome scanning
- GC content influences stability

Clinical relevance:

- mRNA vaccines (modRNA)
- mRNA decay defects → cancer progression

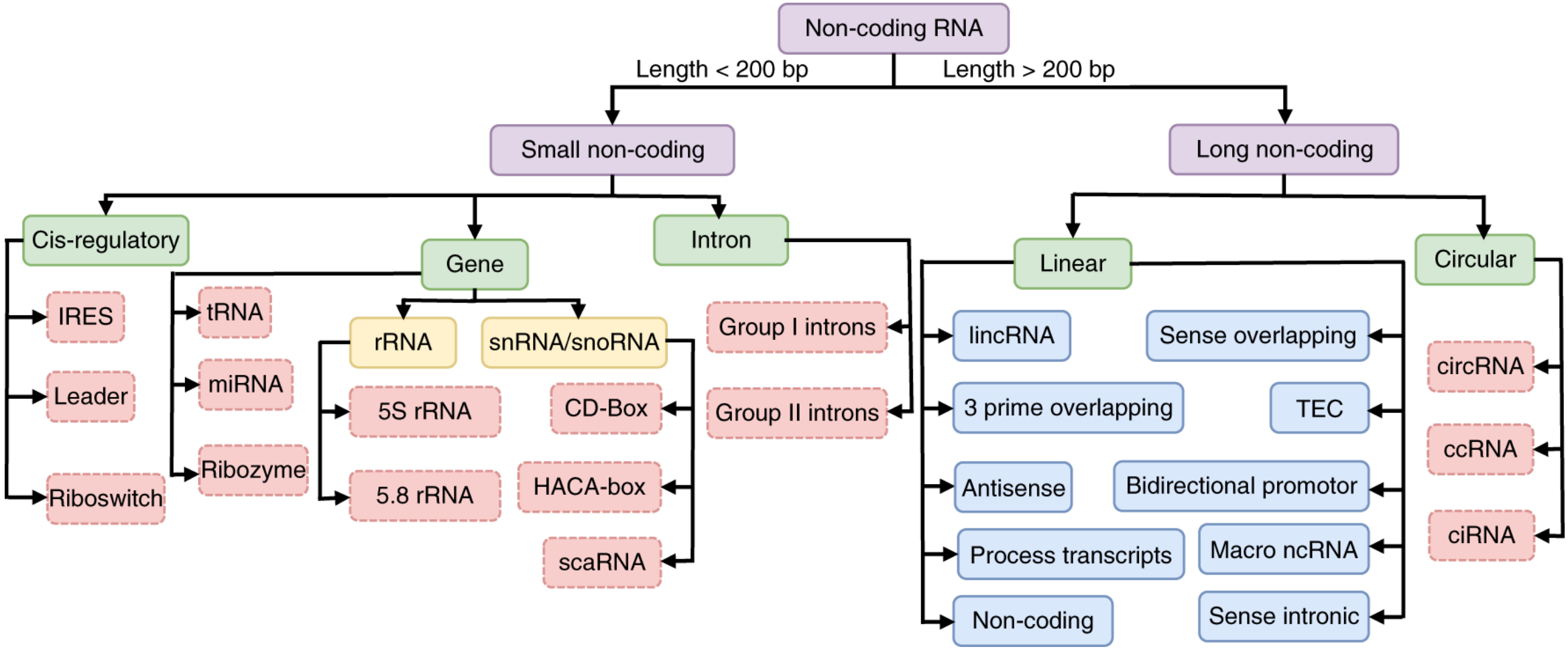
B. Non-Coding RNAs

RNA Type	Definition	Main Functions
tRNA (Transfer RNA)	A small RNA (70–90 nt) folded into a cloverleaf shape that carries amino acids.	- Brings amino acids to the ribosome during translation- Matches codon on mRNA using anticodon- Ensures correct amino acid is added
rRNA (Ribosomal RNA)	The main structural and catalytic RNA inside ribosomes.	- Forms the framework of ribosomes- Catalyzes peptide bond formation (acts as a ribozyme)- Ensures correct alignment of mRNA and tRNA
snRNA (Small Nuclear RNA)	Short RNAs located in the nucleus that form part of the spliceosome.	- Recognize exon–intron boundaries- Catalyze removal of introns from pre-mRNA
snoRNA (Small Nucleolar RNA)	Small RNAs located in the nucleolus involved in modifying rRNA.	- Guide rRNA chemical modification- Ribose methylation and pseudouridylation- Assist rRNA processing

B. Non-Coding RNAs

RNA Type	Definition	Main Functions
miRNA (MicroRNA)	Very small (~22 nt) regulatory RNAs made from hairpin precursors.	- Bind 3′ UTR of mRNA- Block translation or promote degradation- Fine-tune gene expression
siRNA (Small Interfering RNA)	Double-stranded RNA, often from viruses or external sources.	- Guides RISC to cut target mRNA- Perfect base pairing leads to mRNA degradation
lncRNA (Long Non-Coding RNA)	Long RNAs (>200 nt) that do not code for proteins but regulate gene activity.	- Scaffold for chromatin modifiers- Guide proteins to DNA- Act as decoys for miRNAs- Regulate transcription
circRNA (Circular RNA)	RNA molecules joined end-to-end forming a closed loop.	- Act as sponges for miRNAs- Regulate gene expression- Very stable due to lack of ends
Ribozymes	RNA molecules with catalytic (enzyme-like) activity.	- Self-splicing- Assist tRNA maturation- Catalyze biochemical reactions

B. Non-Coding RNAs



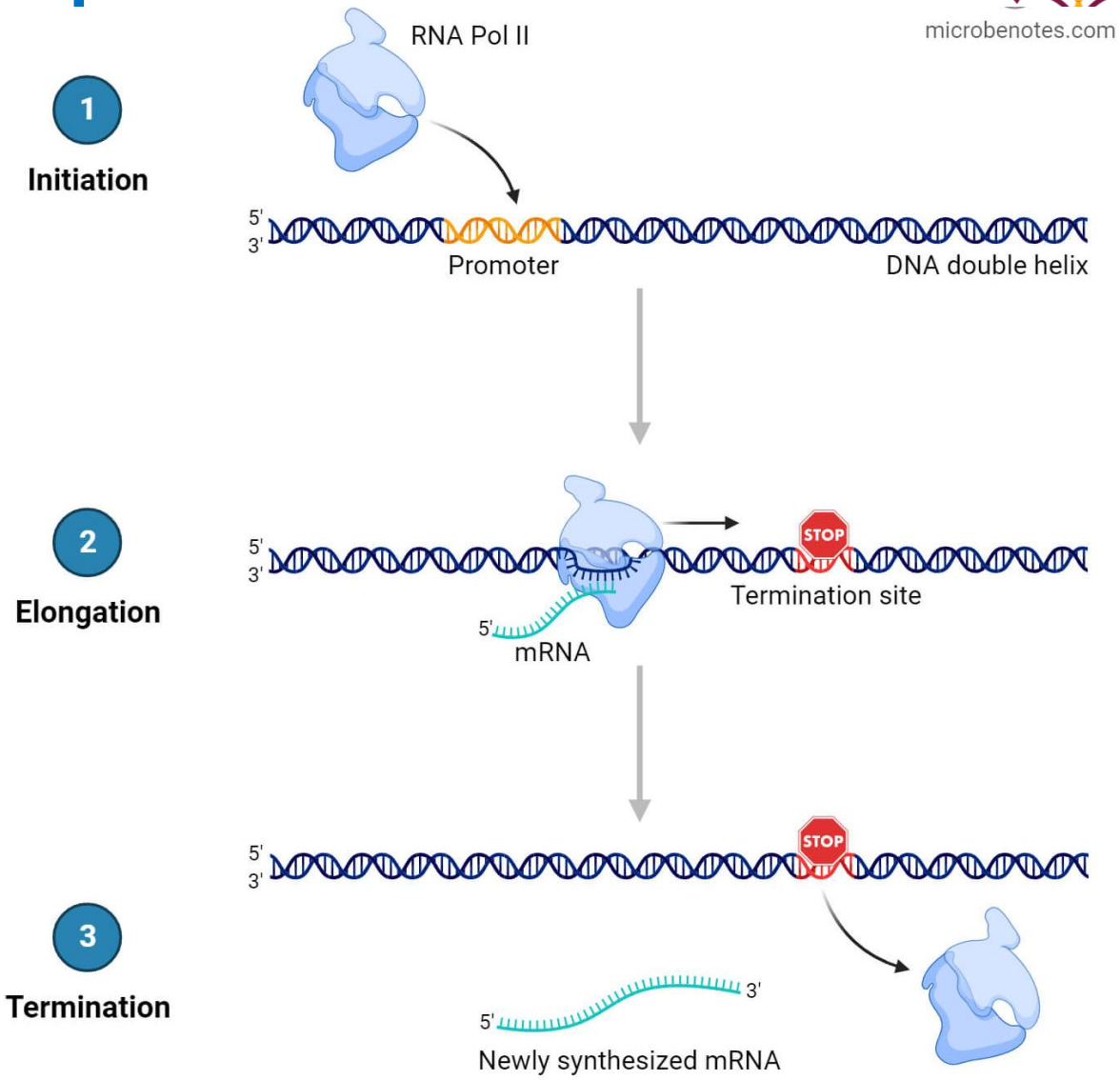
Stages of Gene Expression

Gene expression is a biological process in which the genetic information contained within genes is translated into functional outcomes. This process includes two main stages:

I. **transcription and**
II. **translation**.

Transcription

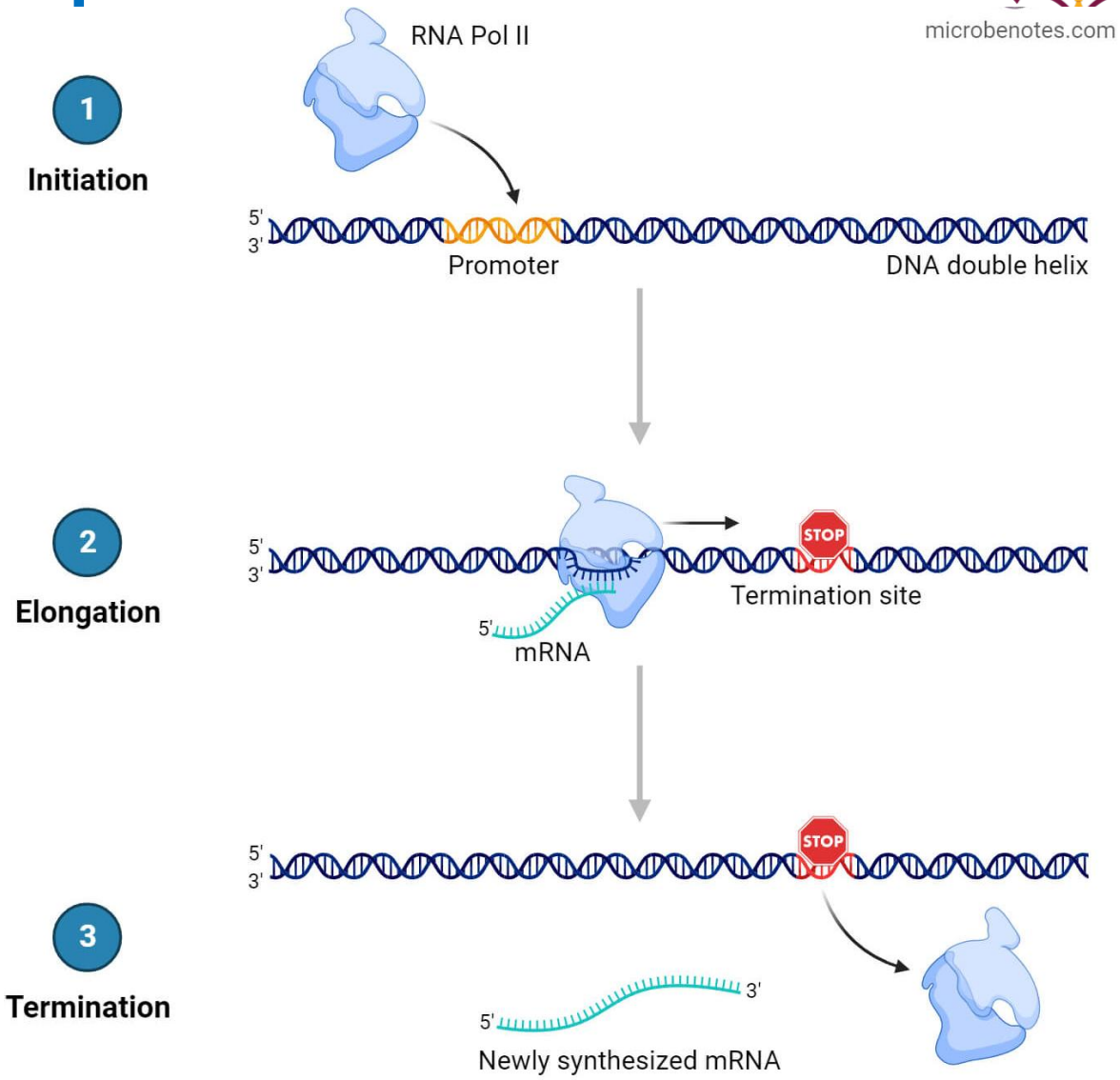
Transcription is the first step in gene expression, where the genetic information encoded in DNA is transcribed into mRNA by an enzyme called **RNA polymerase**.



Transcription

Initiation

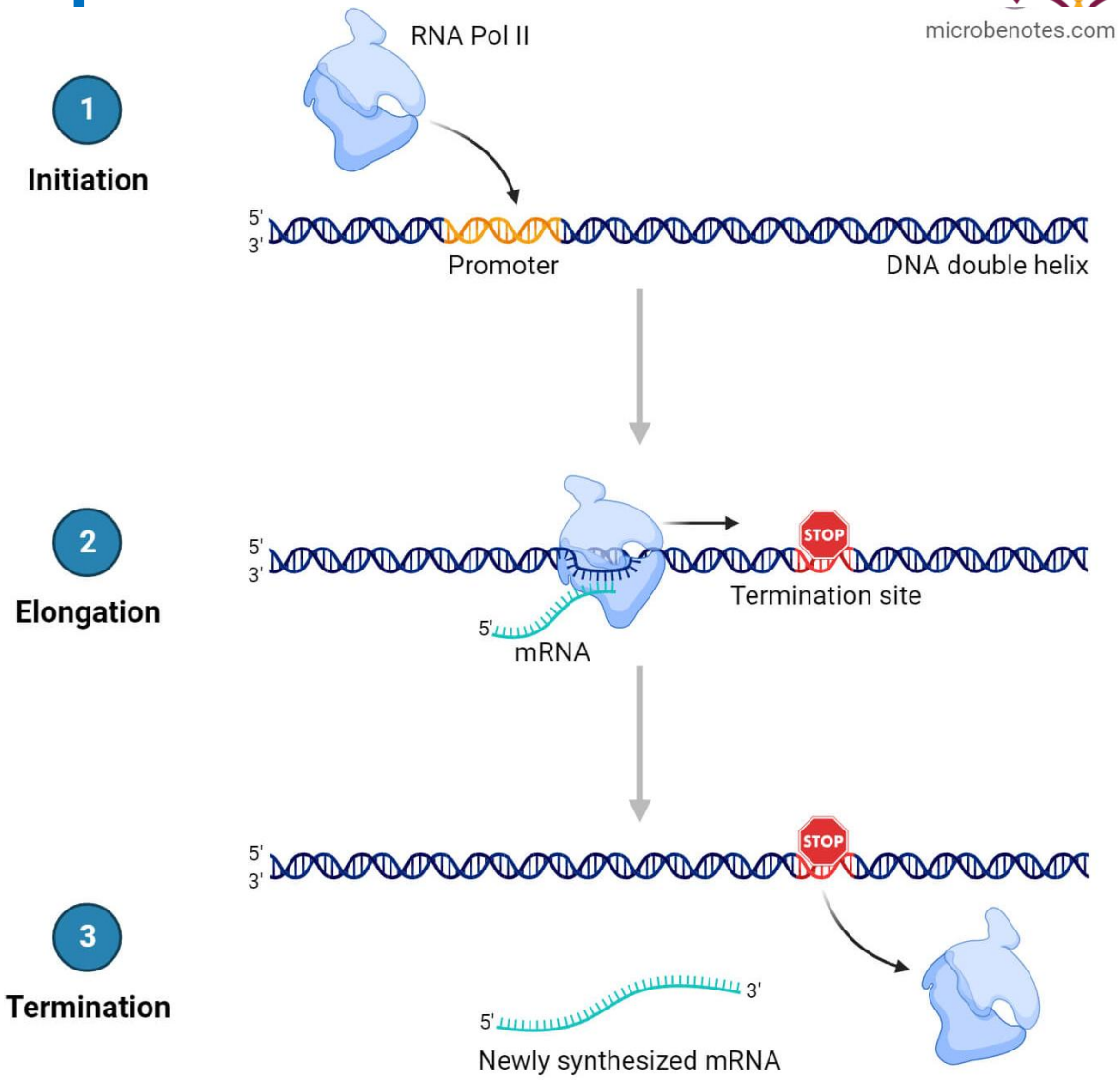
- **Initiation** begins when RNA Polymerase II recognizes and binds to the promoter, assisted by transcription factors (not shown here).
- The promoter determines the transcription start site and direction.
- Local unwinding of DNA occurs, creating an **open complex** so RNA synthesis can begin.
- This step establishes the **reading frame** and ensures that the correct gene is transcribed.



Transcription

Elongation

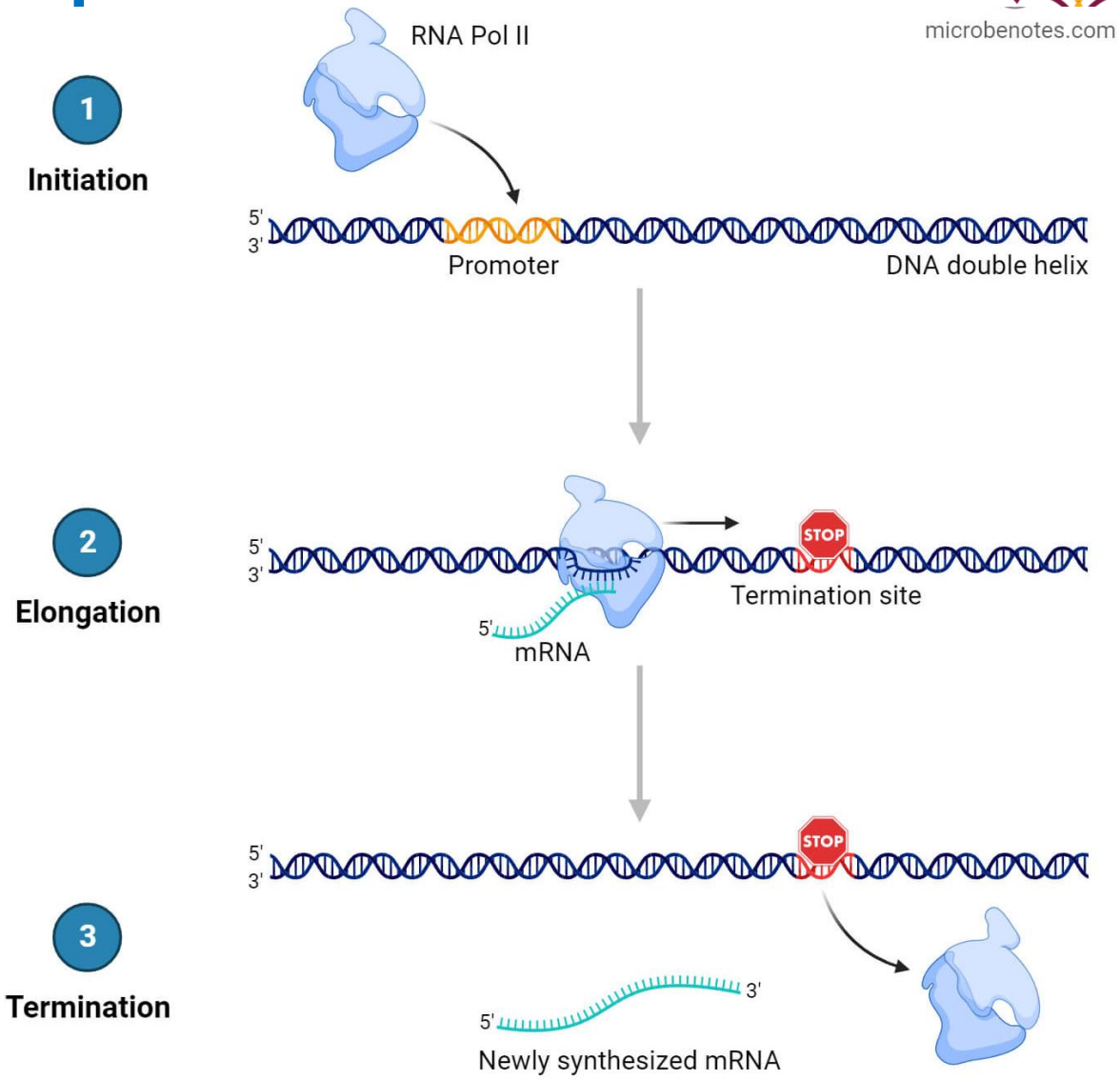
- RNA Polymerase II moves along the DNA template strand.
- The enzyme reads the DNA template **in the 3′ → 5′ direction**, while synthesizing RNA **in the 5′ → 3′ direction**.
- A complementary **mRNA strand (shown in green)** is being synthesized.
- The polymerase travels toward a marked **termination site**.



Transcription

Termination

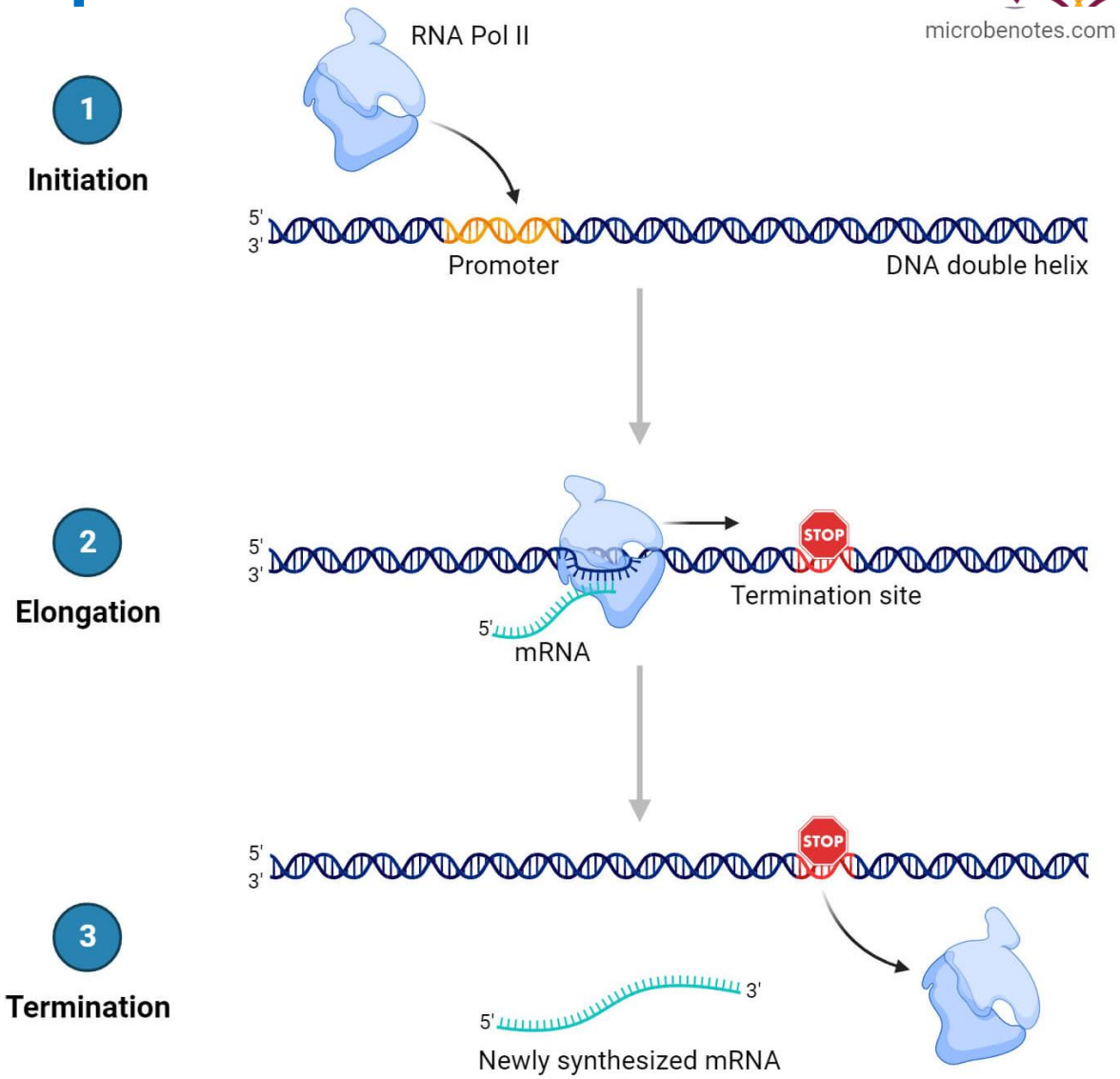
- RNA Polymerase reaches the termination sequence, indicated by a stop symbol.
- The enzyme dissociates from the DNA template.
- A full-length mRNA molecule is released.



Transcription

Initiatio
Elongation
Termination

- YouTube
- https://www.youtube.com/watch?v=bKIpDtJdK8Q



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