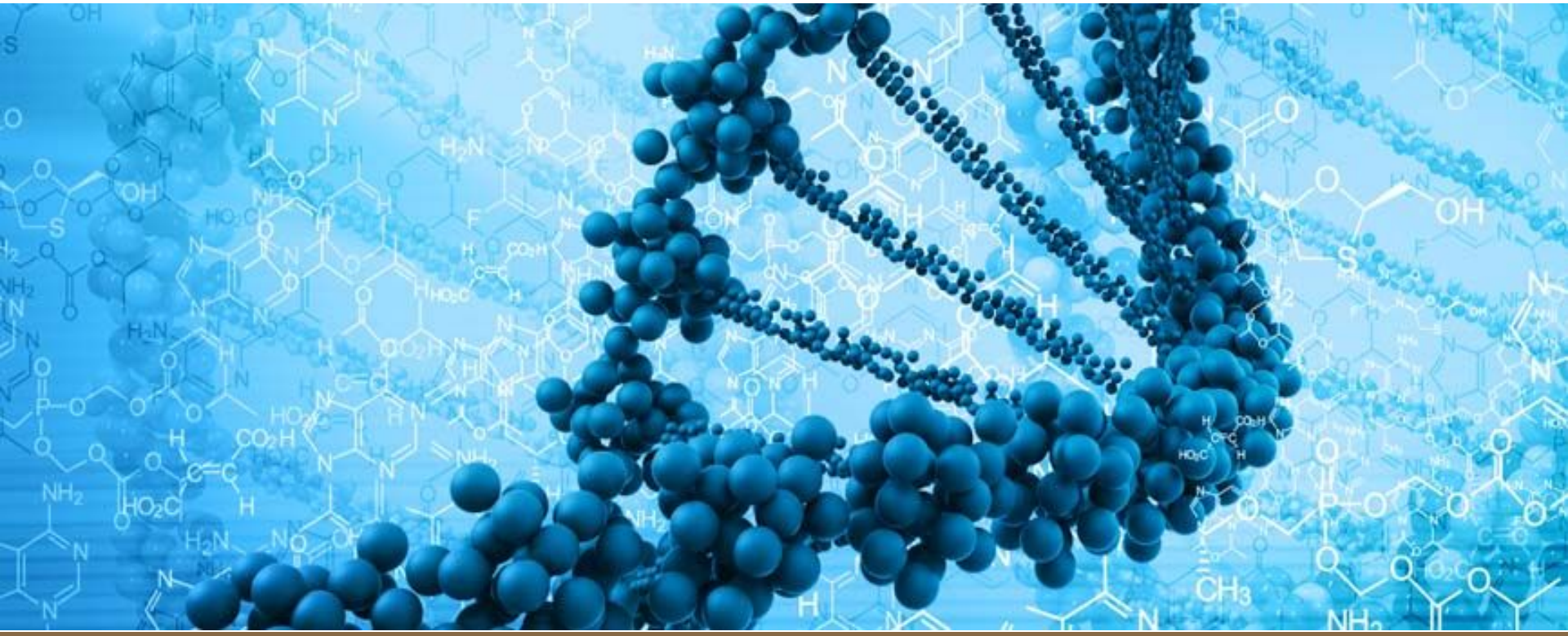
Lecture B6:
DNA Replication, Transcription and Translation



Learning Outcomes

At the end of the lecture students should be able to:

- Describe the process of DNA replication
- Explain the relationship between the processes of DNA transcription, RNA processing and protein synthesis
- **Text reference:** *Campbell Concepts*, 10.4-10.15

DNA and genetics

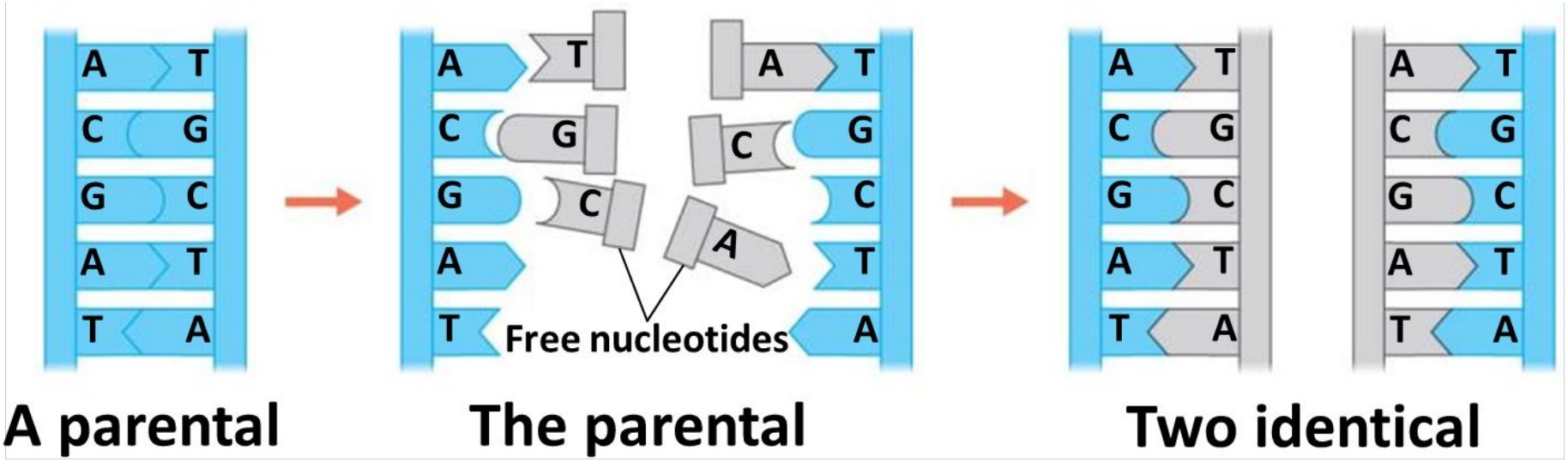
- **Genetics** is the study of inheritance – how characteristics are passed from parents to offspring
- The hereditary information is encoded in **DNA** and passed from one generation to the next by precise copying
- Because of this DNA is frequently referred to as the “genetic molecule”

DNA replication

- **DNA replication** is the biological process of producing two identical copies (replicas) of DNA from one original DNA molecule
- Necessary precursor to **cell division** (next lecture)

- DNA replication is **semiconservative**.
  - The two DNA strands separate and each strand becomes a template for the assembly of a complementary strand
  - Each new DNA helix has **one old strand** with one new strand

DNA replication is semiconservative

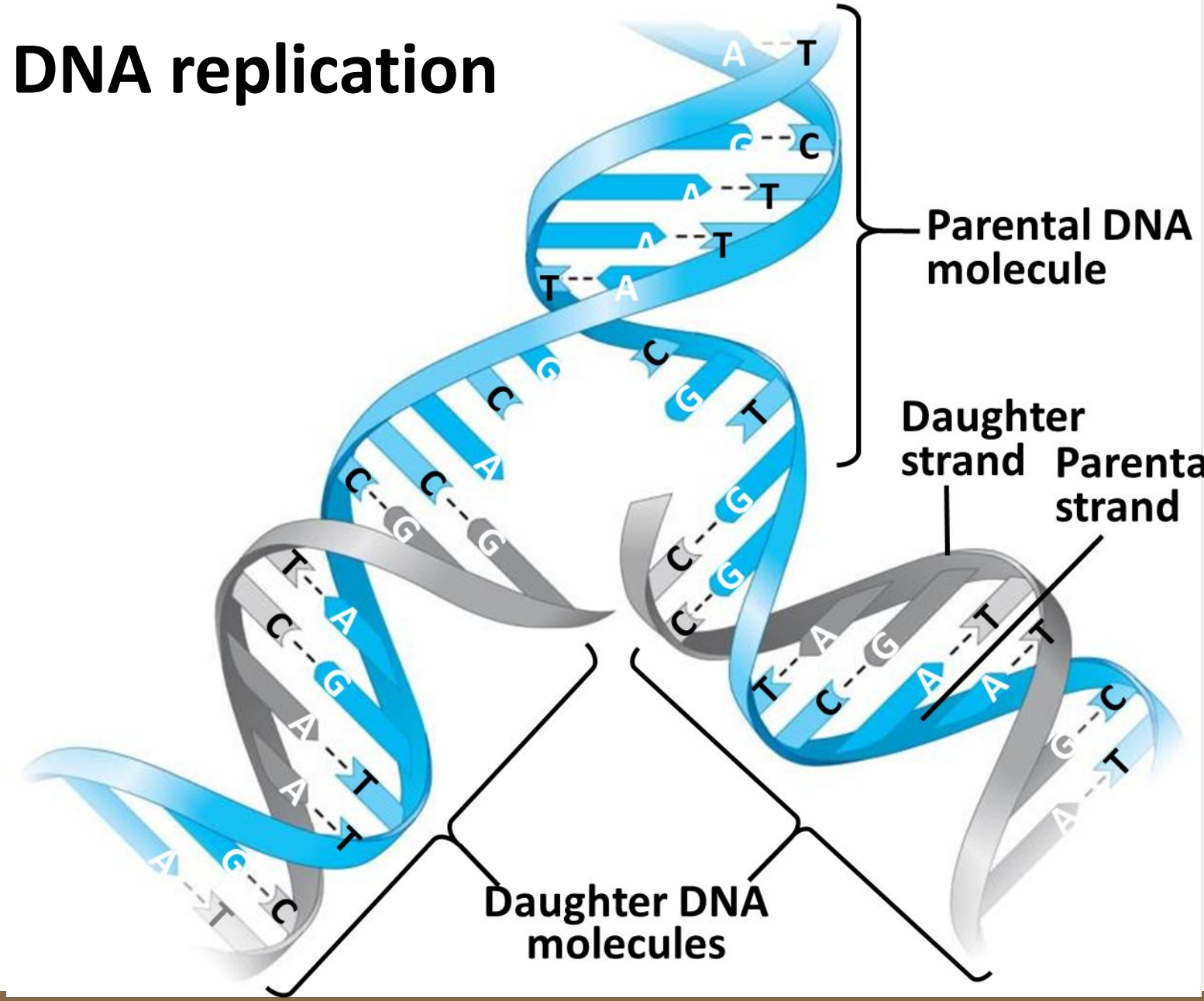


A parental molecule of DNA

The parental strands separate and serve as templates

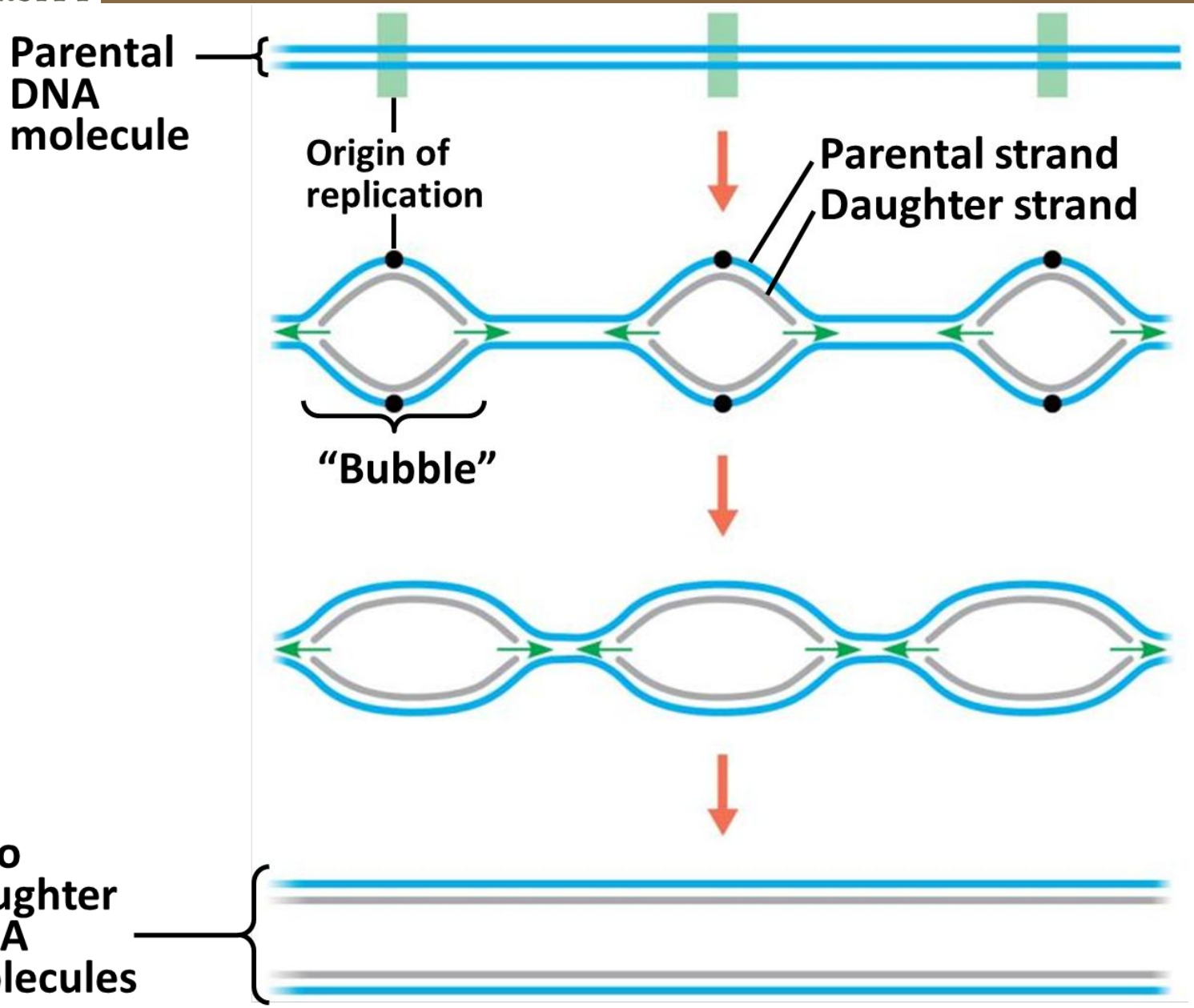
Two identical daughter molecules of DNA are formed

DNA replication

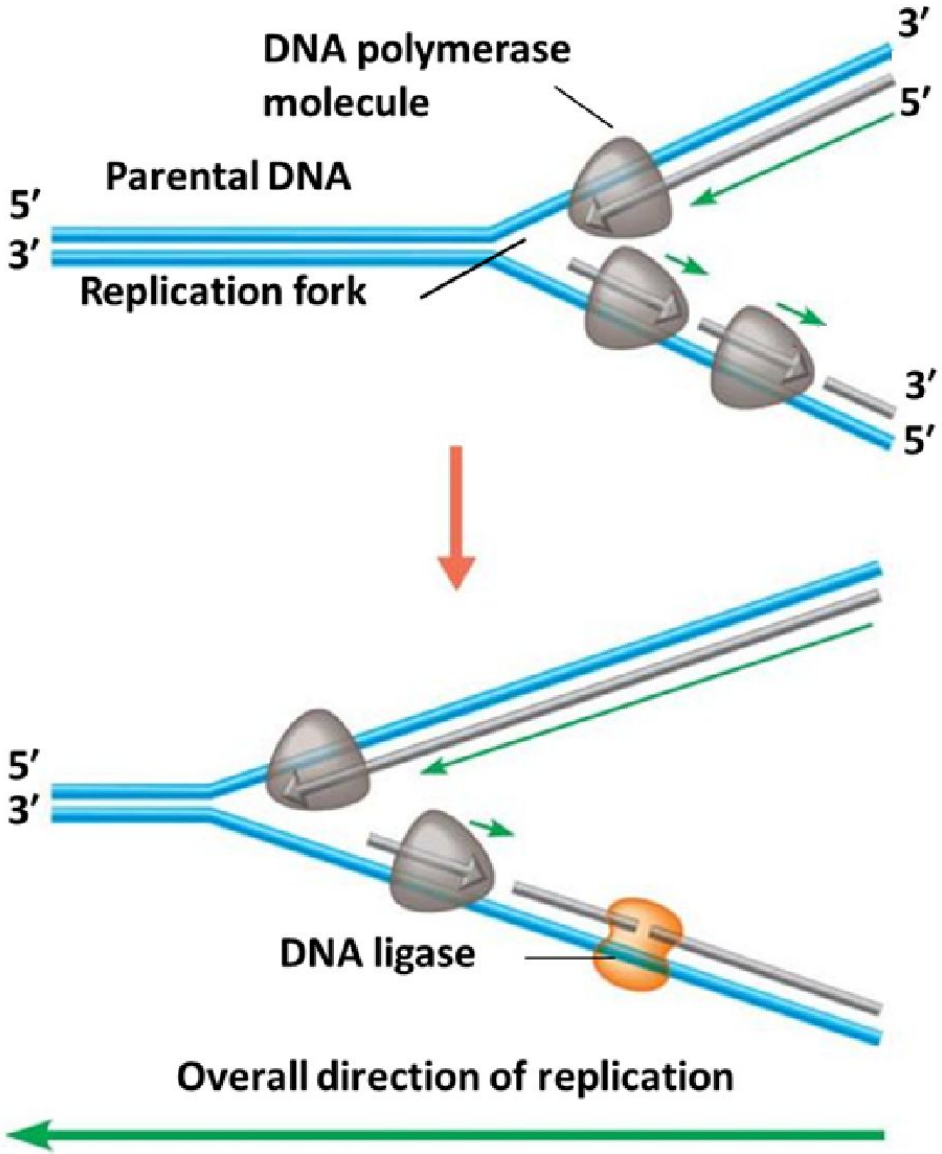


DNA replication proceeds in two directions at many sites simultaneously

- Replication of a DNA molecule begins at sites called **origins of replication**, short stretches of DNA that have a specific sequence of nucleotides.
- Proteins that initiate DNA replication attach to the DNA at the origin of replication and separate the two strands of the double helix
- Replication then proceeds in both directions, creating replication "bubbles."


Parental DNA molecule
Origin of replication
Parental strand
Daughter strand
"Bubble"
Two daughter DNA molecules

Enzymes involved in replication



- **DNA polymerases** add nucleotides to the growing strands
- **DNA ligase** ties short DNA fragments together
- DNA polymerases and DNA ligase also repair DNA damaged by harmful radiation and toxic chemicals

- DNA replication ensures that all the somatic cells in a multicellular organism carry the same genetic information
- If the process is completed without errors, two daughter cells identical to the original will form.
- However, mistakes may occur during this complicated process – these can result in **mutations**

Gene expression

Gene expression

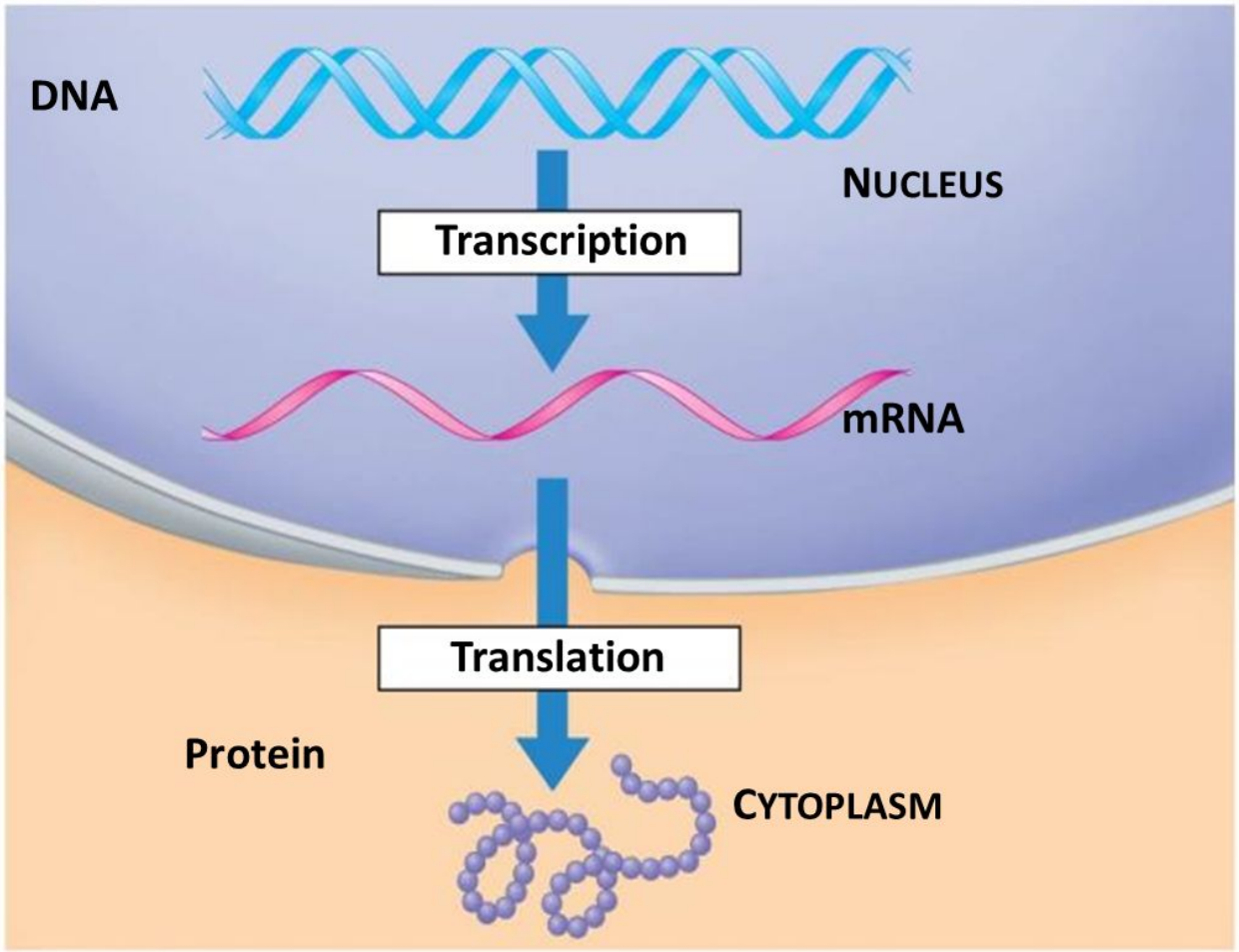
- The expression of the information encoded in DNA is a complicated, multi-step process
- The DNA program ultimately directs the development of biochemical, anatomical and physiological traits of the cell and individual

The flow of information is from DNA to RNA to protein

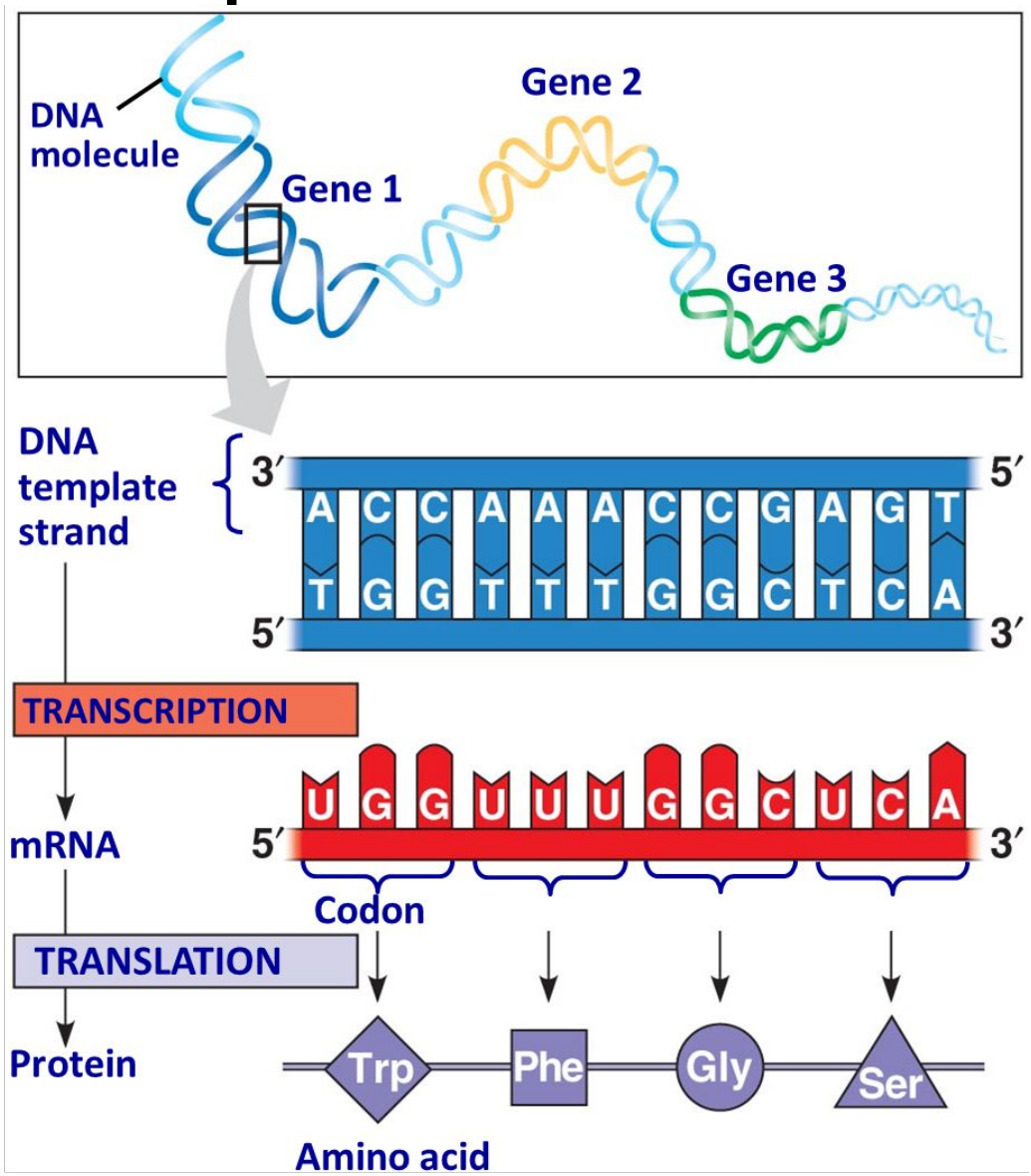
- DNA specifies traits by dictating protein synthesis.
- The molecular chain of command is from DNA in the nucleus to RNA and RNA in the cytoplasm to protein.

Genes control characteristics through the production of proteins

- **Transcription** is the synthesis of **messenger RNA** (**mRNA**) using DNA as a template.
- **Translation** is the synthesis of proteins under the direction of mRNA.



Transcription and Translation

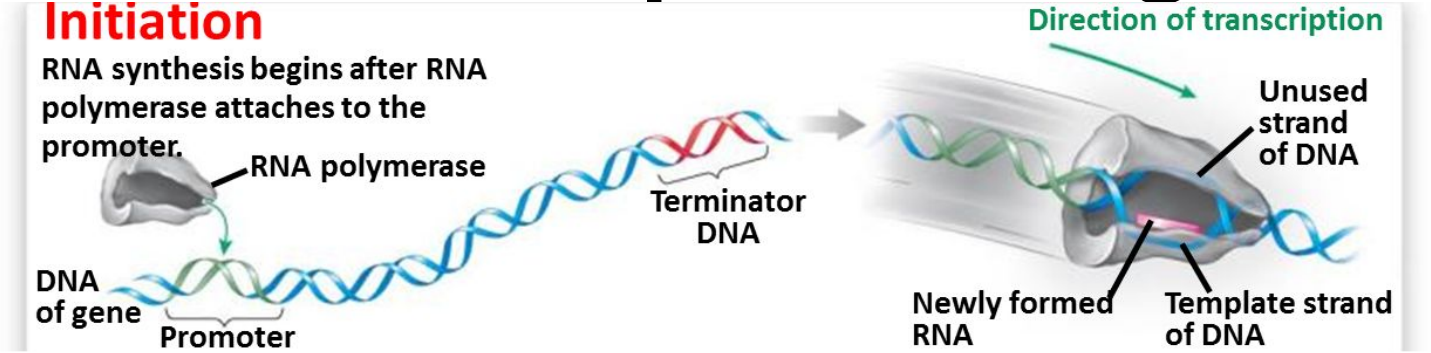


Transcription

Transcription produces mRNA

- Transcription of a gene occurs in three main steps:
  1. **Initiation**: **RNA polymerase** attaches to a DNA region called the **promoter** and starts RNA synthesis
  2. **Elongation**: The newly formed RNA strand grows
  3. **Termination**: The RNA polymerase reaches the **terminator DNA** and detaches from both the newly made **RNA transcript** and the DNA

The transcription of a gene



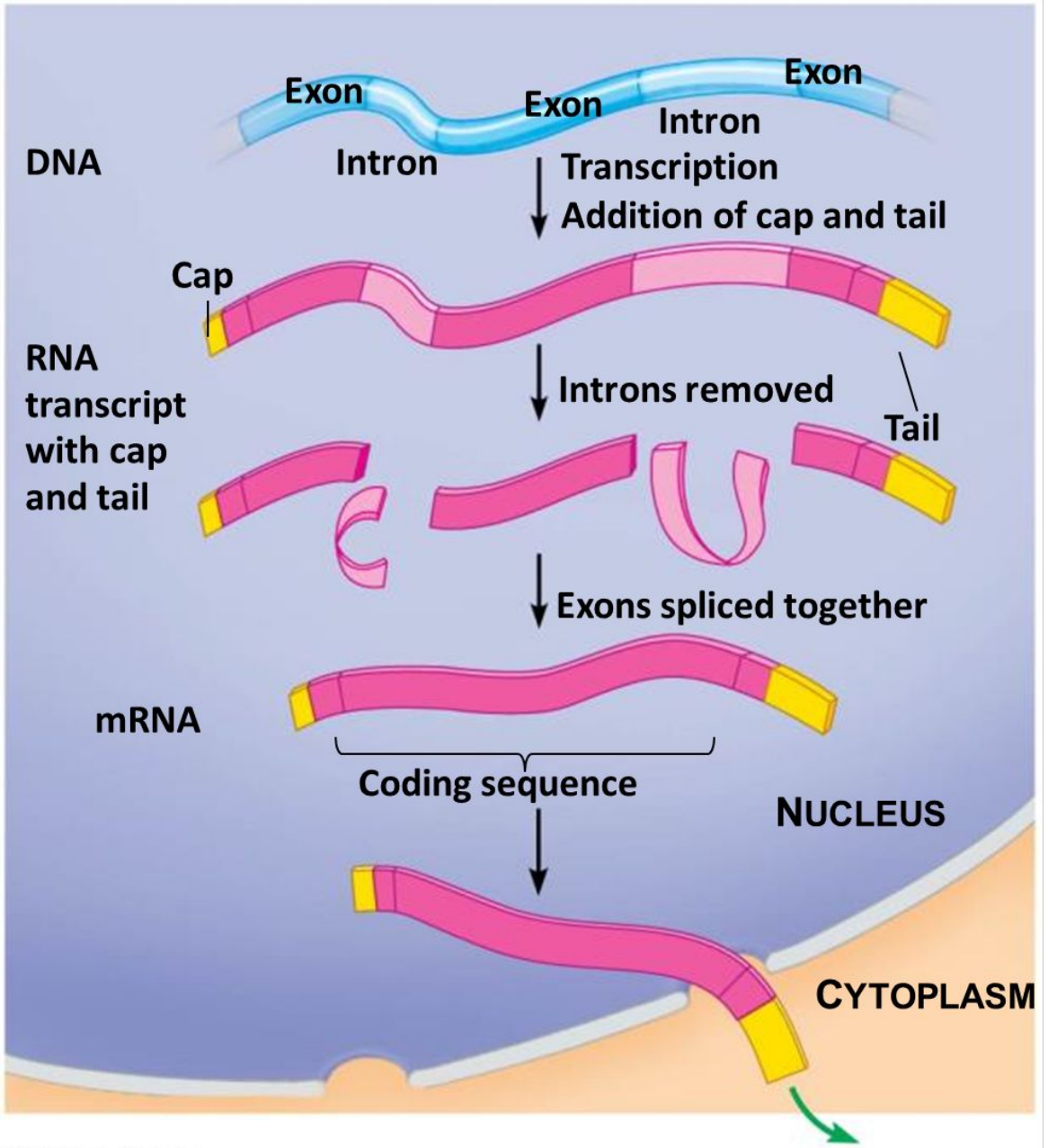
Post-transcriptional modification

- In **prokaryotes**, the RNA transcript is ready for immediate translation
- **Eukaryotic** mRNA is more complex than prokaryotic
  - Contains **introns** (interrupting sequences) that separate **exons** (the coding regions)
- It is processed in the nucleus and then exported for translation

Eukaryotic RNA processing

- First there is **RNA splicing**
  - Introns are removed and the exons are joined to produce a continuous coding sequence.
- Then a **cap and tail** of extra nucleotides are added to the ends of the mRNA to:
  - Help the export of the mRNA from the nucleus
  - Protect the mRNA from degradation by cellular enzymes
  - Help **ribosomes** bind to the mRNA
- **The cap and tail are not translated into protein**.

Production of eukaryotic mRNA



Translation

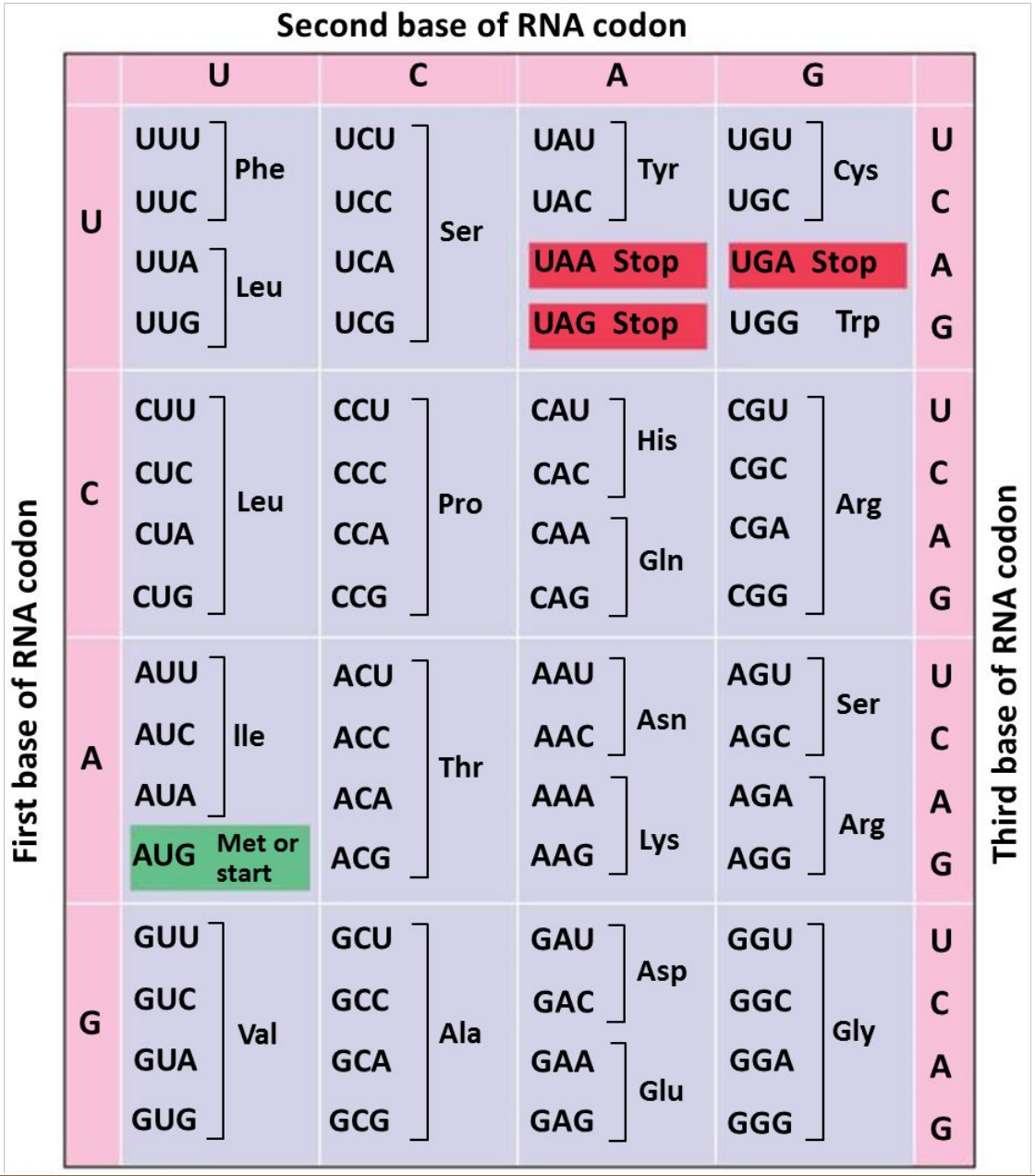
Information written in DNA is translated into proteins

- The sequence of nucleotides in DNA provides a code for constructing a protein
  - This requires a **conversion** of a **nucleotide sequence** to an **amino acid sequence**
- The flow of information from gene to protein is based on a **triplet code –** three-base "words" called **codons**

The genetic code dictates how codons are translated into amino acids

- The **genetic code** directs the amino acid translation of each of the nucleotide triplets.
  - Three nucleotides specify one amino acid.
  - Of the possible **64 codons**, **61** code for **amino acids** and **3 codons** signal the end of translation.
  - **AUG** codes for methionine and signals the **start** of translation.
  - **UAA, UGA** and **UAG** are the **stop** codons.

Dictionary of the genetic code

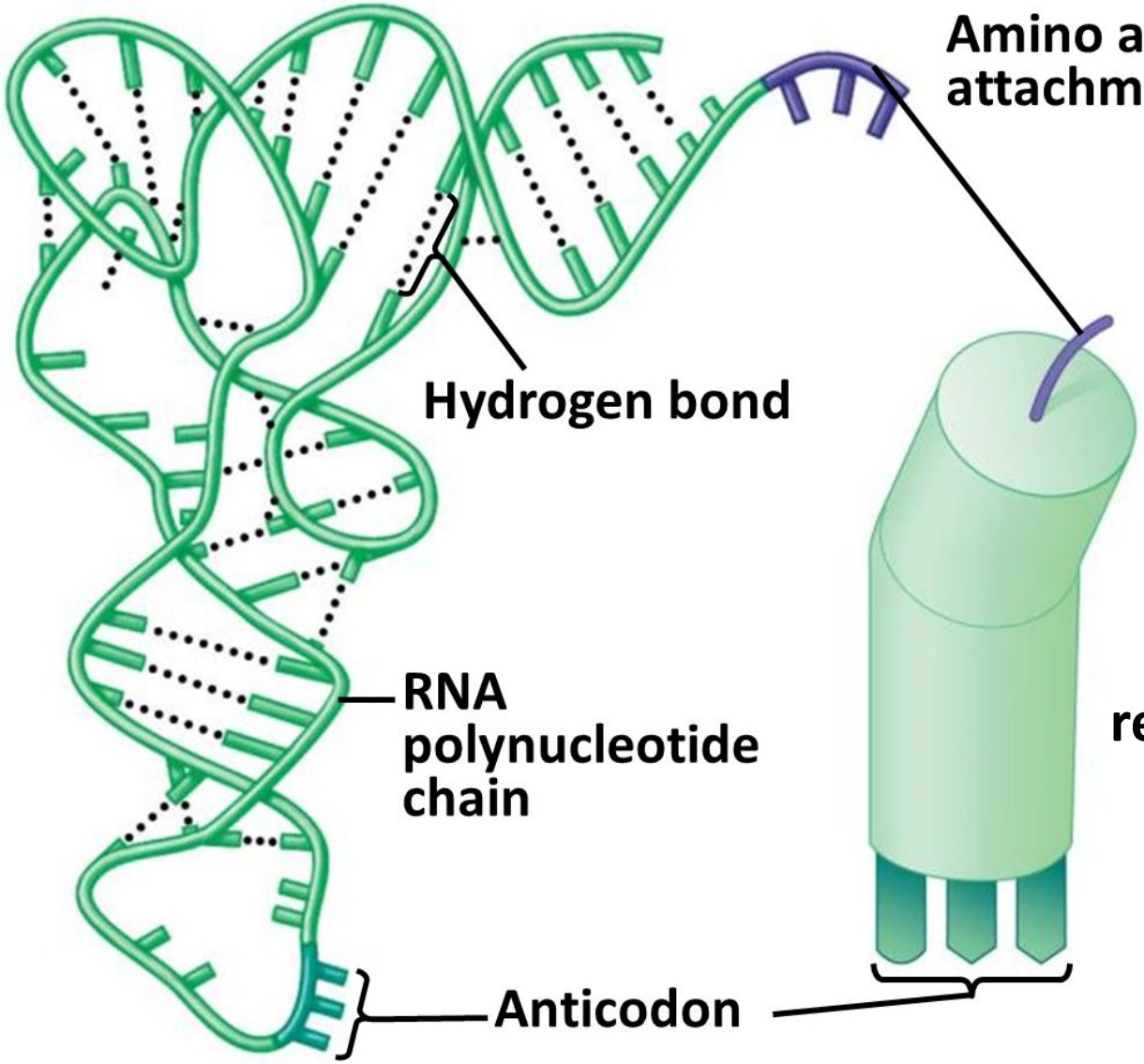


Characteristics of the genetic code

- The genetic code is
  - *Redundant*: some amino acids have more than one codon
  - *Unambiguous*: each codon codes for only one amino acid
  - *(Nearly) universal*: the genetic code is shared by organisms from the simplest bacteria to the most complex plants and animals

Translation of the genetic message

- Translation is performed by **transfer RNA** (**tRNA**) molecules
- Transfer RNA molecules do this by
  - picking up the appropriate amino acid
  - using a special triplet of bases, called an **anticodon**, to recognize the appropriate codons in the mRNA.



A simplified representation of a tRNA

A tRNA molecule, showing its polynucleotide strand and hydrogen bonding

Ribosomes build polypeptides

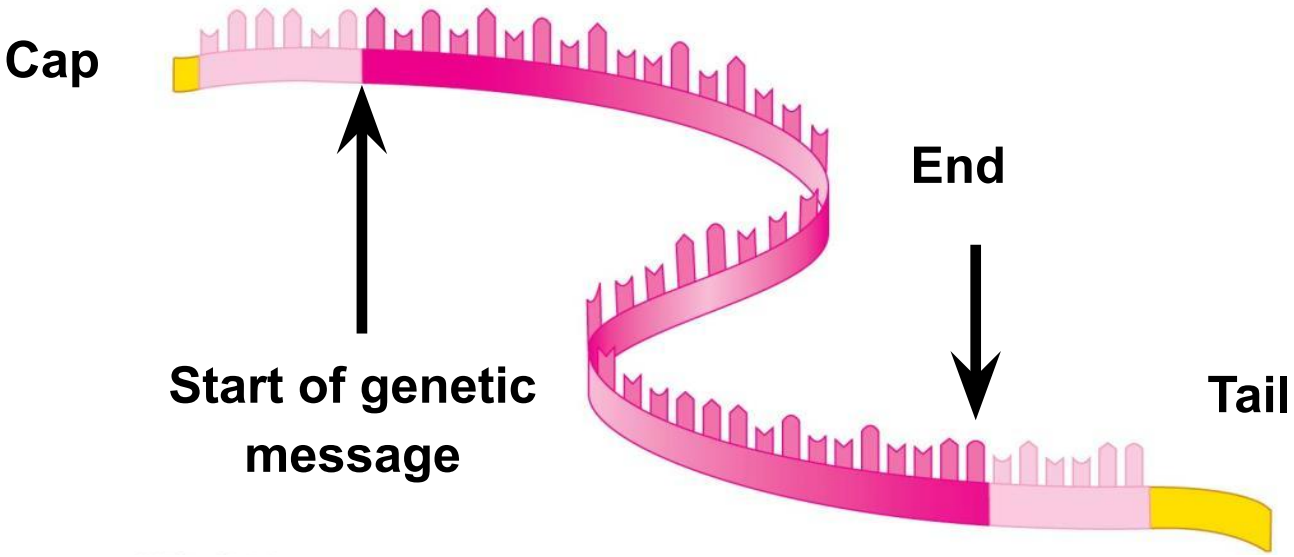
- Translation occurs on the surface of the **ribosome**.
  - Ribosomes coordinate the interaction of mRNA and tRNA and, through this, the synthesis of polypeptides.
- Ribosomes have two subunits: small and large.
- Each subunit is composed of **ribosomal RNAs** (rRNA) and proteins.
- Ribosomal subunits come together during **translation**.
- Ribosomes have binding sites for mRNA and tRNAs.

Translation produces polypeptides

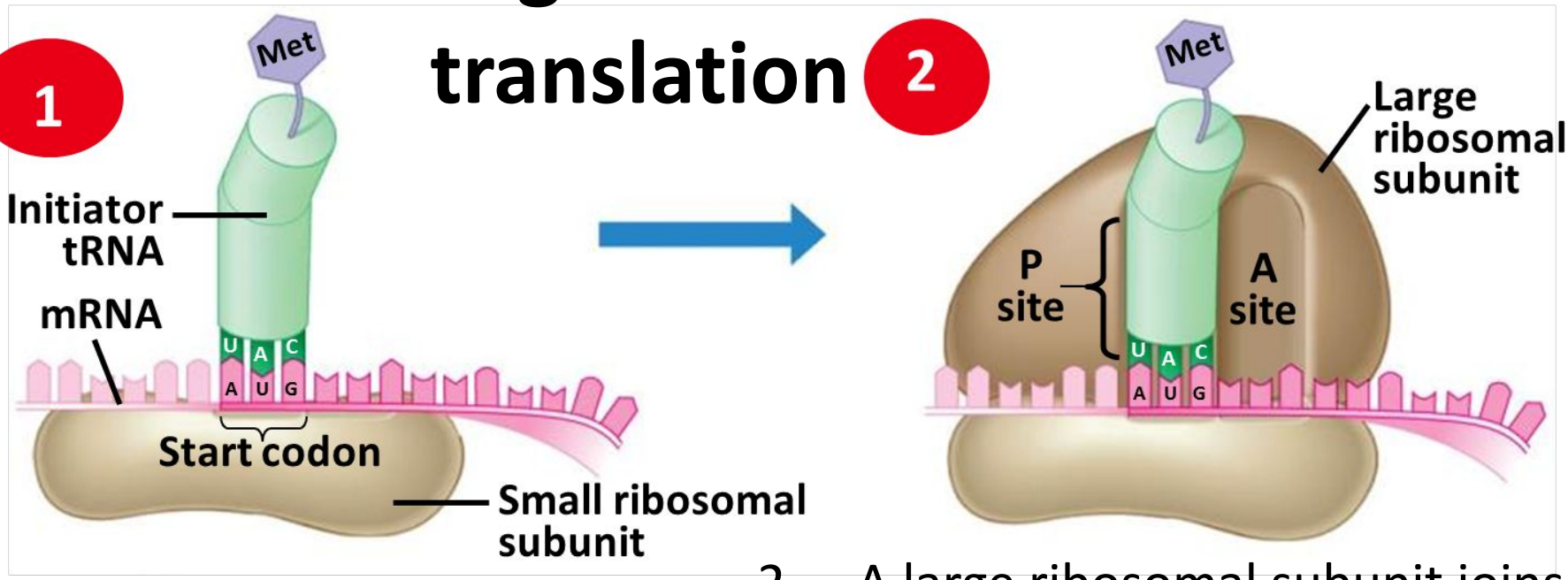
- Translation can be divided into the same three phases as transcription:
  1. Initiation
  2. Elongation
  3. Termination

An initiation codon marks the start of the mRNA message

- Initiation brings together
  - **mRNA**, a **tRNA** bearing the first amino acid, and the **two subunits** of a ribosome.
  - Initiation establishes where translation will begin.



The two stages of initiation in translation

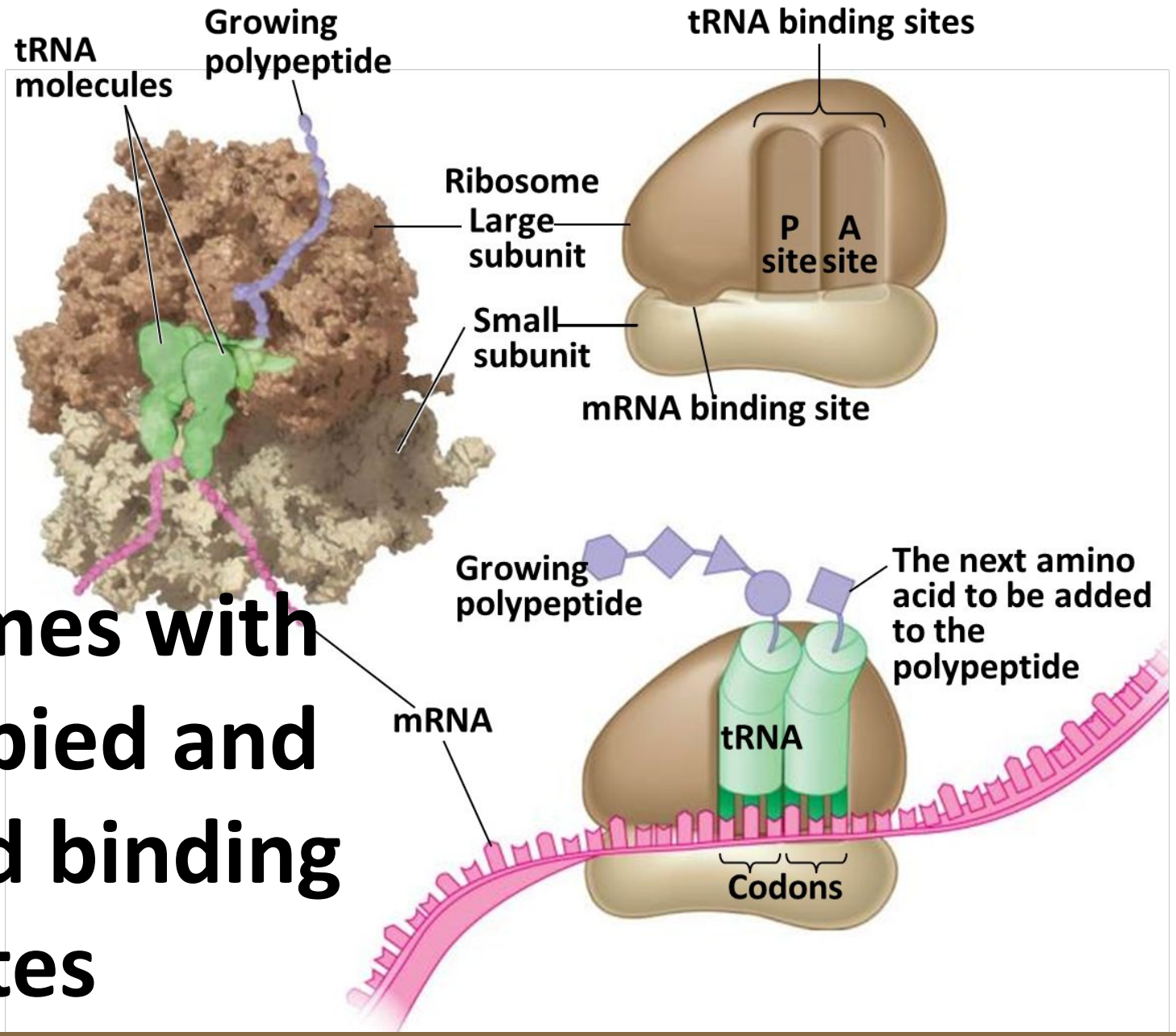


1. mRNA binds to a small ribosomal subunit, and an **initiator tRNA** binds to mRNA at the **start codon** that reads AUG and codes for methionine (first tRNA has the anticodon UAC).

2. A large ribosomal subunit joins the small subunit, allowing the ribosome to function.

- The first tRNA occupies the **P site** (growing **polypeptide**).
- The **A site** (next **amino-acid**-bearing tRNA).

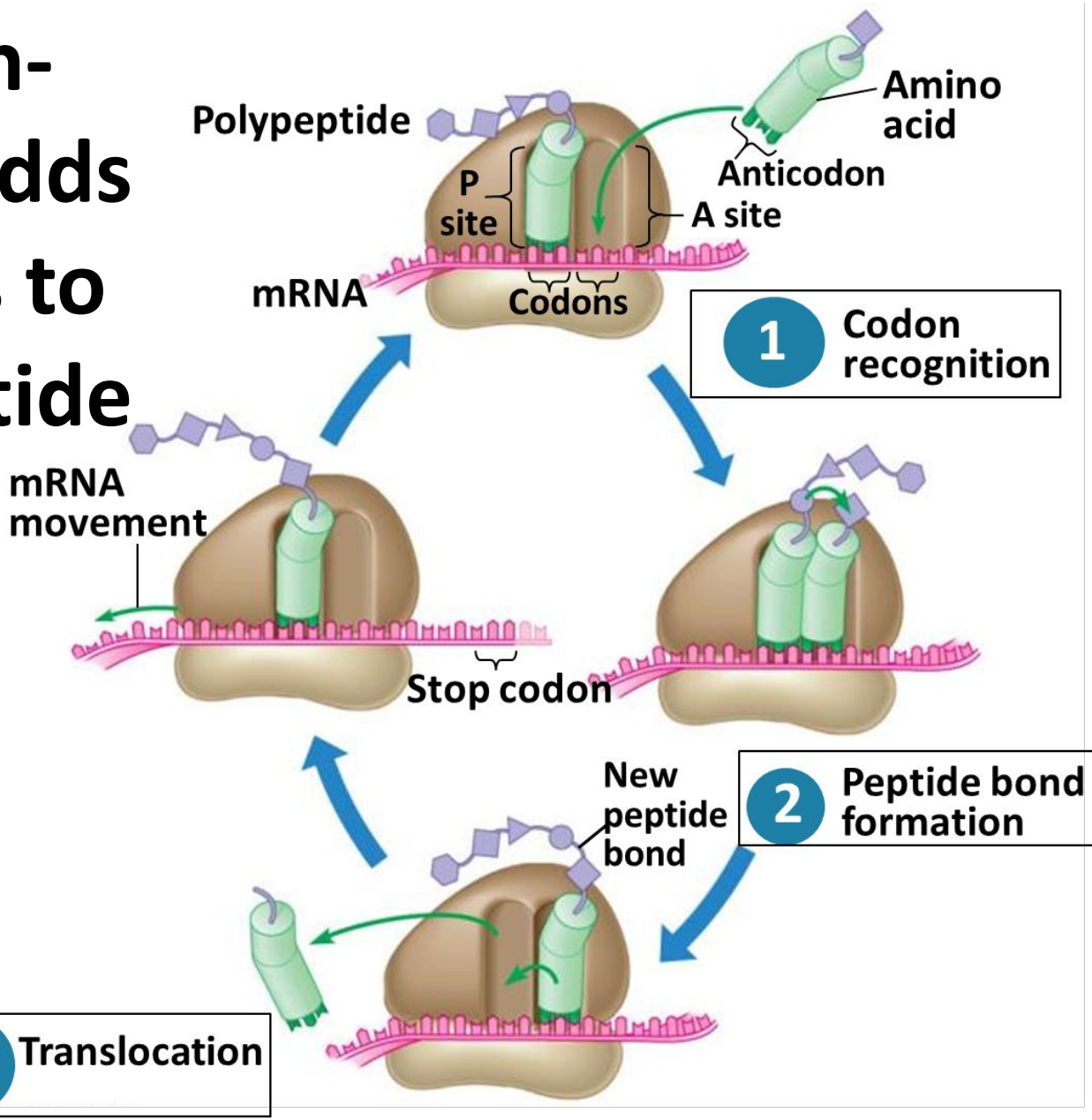
Ribosomes with unoccupied and occupied binding sites



Elongation adds amino acids to the polypeptide chain

- Once initiation is complete, amino acids are added one by one to the first amino acid (**elongation** process).
- This occurs in three steps:
  1. The anticodon of an incoming tRNA molecule, carrying its amino acid, pairs with the mRNA codon in the A site of the ribosome.
  2. The polypeptide separates from the tRNA in the P site and attaches by a new peptide bond to the amino acid carried by the tRNA in the A site.
  3. The P site tRNA (now lacking an amino acid) leaves the ribosome, and the ribosome translocates (moves) the remaining tRNA (which has the growing polypeptide) from the A site to the P site.

Translation- Elongation adds amino acids to the polypeptide chain

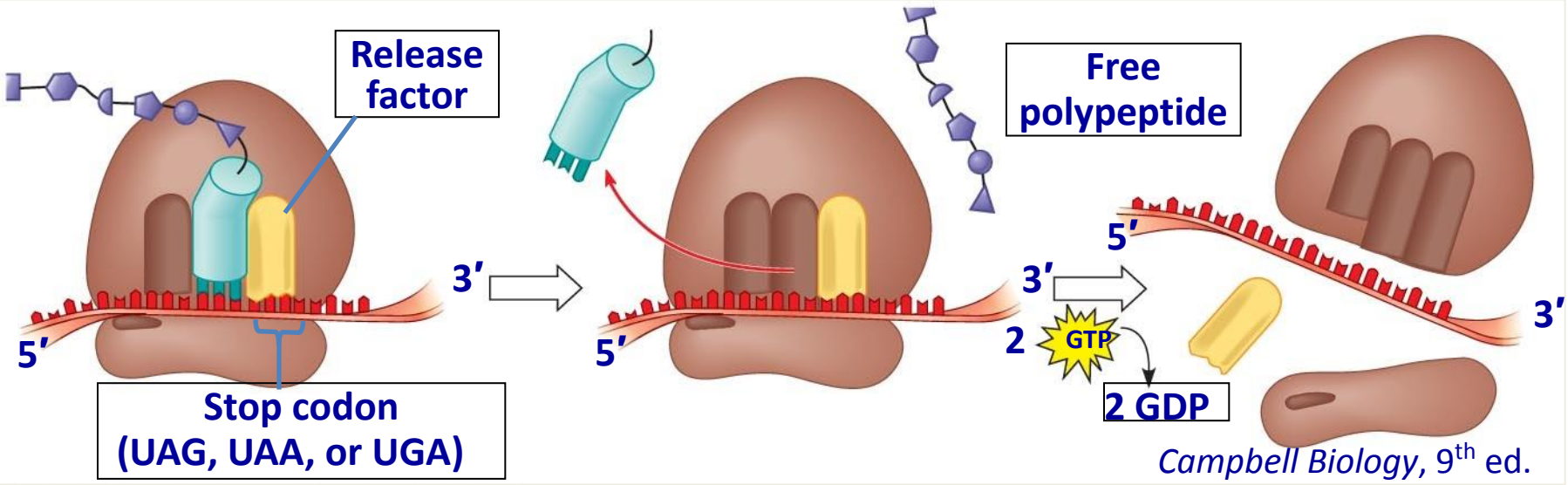


Reminder:

A-site: Amino acid

P site: polypeptide

Elongation adds amino acids to the polypeptide chain until a stop codon terminates translation



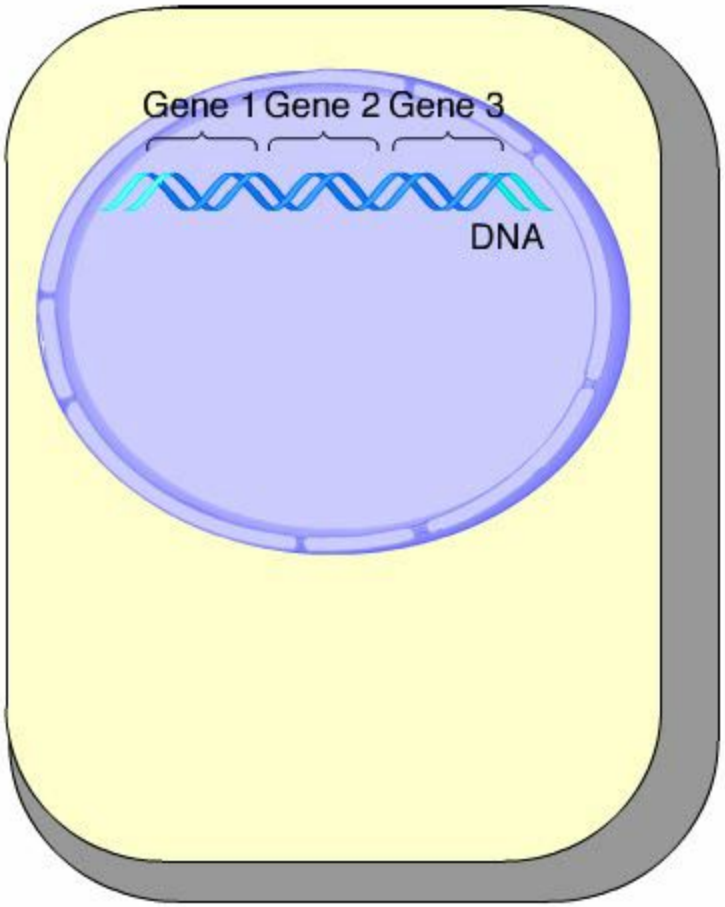
Campbell Biology, 9th ed.

- Stop codon comes into A site
- Release factor binds
- Energy input
- The ribosome splits back into its separate subunits
- New protein is released

Summary

- Genes are expressed when DNA directs protein synthesis
- During gene expression, DNA is **transcribed** to mRNA, which is then **translated** to protein
- Transcription in eukaryotes happens in the nucleus
- Translation is carried out by the ribosomes

Animation: Transcription



Animation: Translation