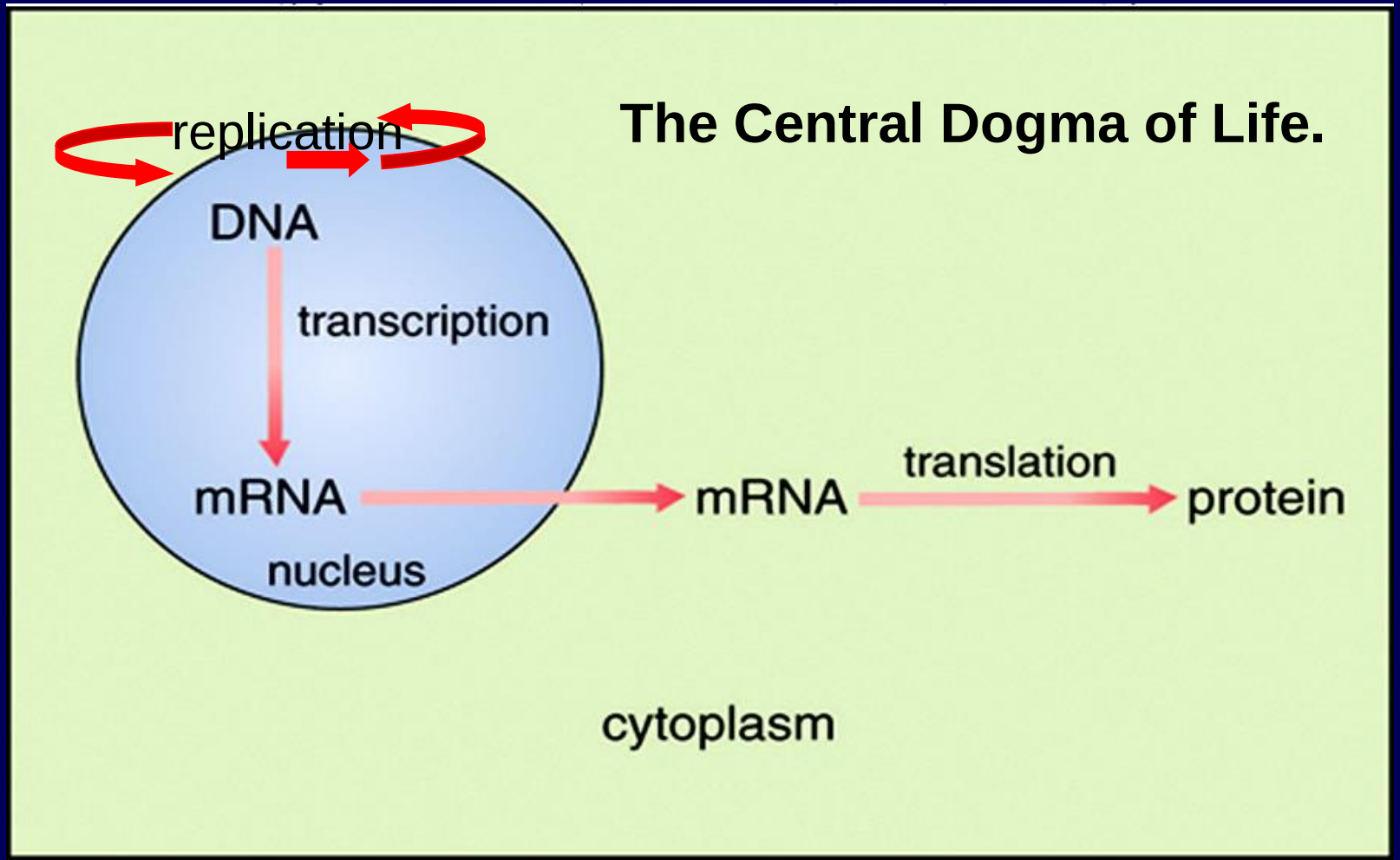
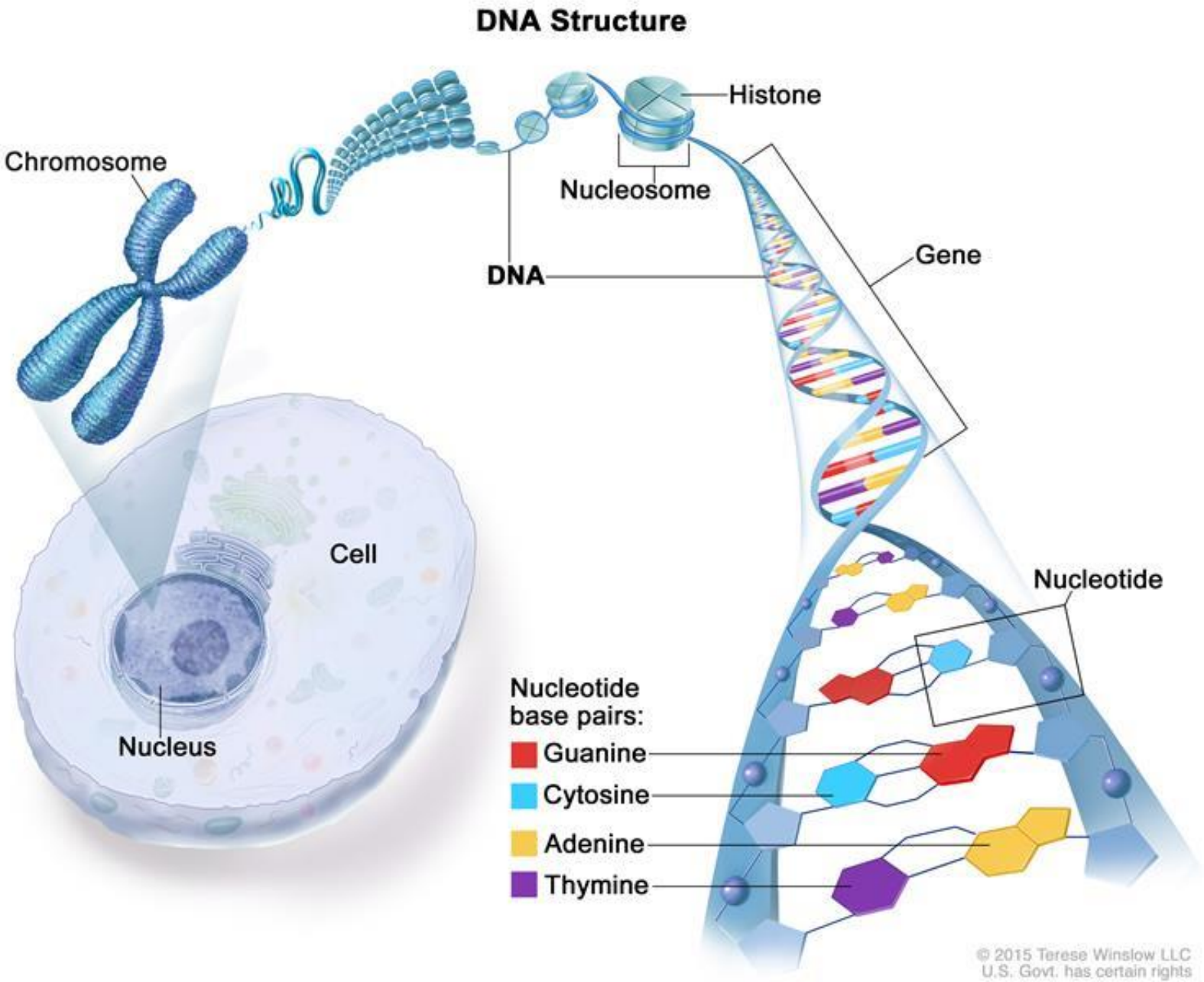
Protein Synthesis




DNA Structure
Histone
Chromosome
Nucleosome
Gene
DNA
Cell
Nucleotide
Nucleotide base pairs:
Guanine
Cytosine
Adenine
Thymine
Nucleus
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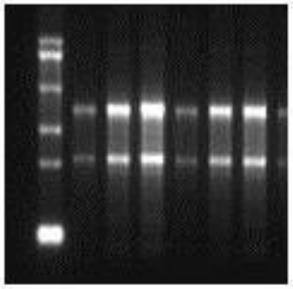
from genotype to phenotype

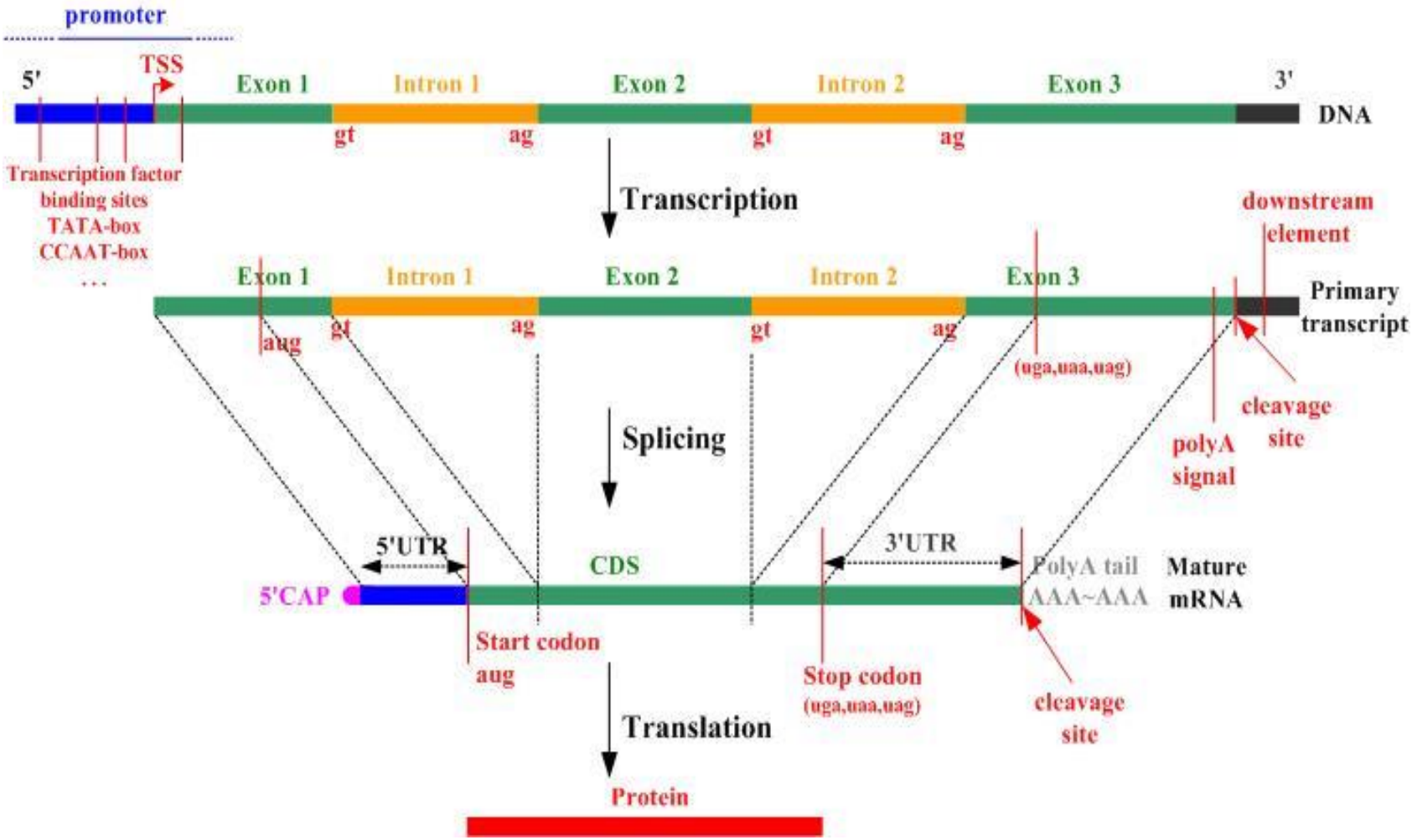
DNA => pre-mRNA => mRNA => => => => protein

↓ transcription ↓ splicing ↓ translation ↓ post-translational modifications

genome **transcriptome** **proteome**



From: Gene Quantification Page by MW Pfaffl



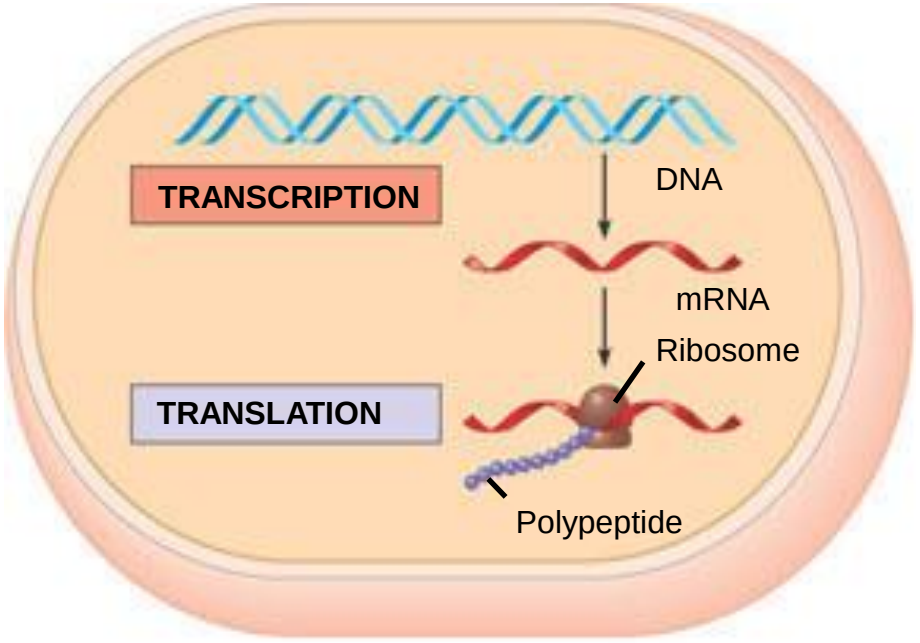
From: Vlad Bajic at BioDiscovery Group, Singapore

Transcription and Translation

- Cells are governed by a cellular chain of command
  - DNA $\rightarrow$ RNA $\rightarrow$ protein
- Transcription
  - Is the synthesis of RNA under the direction of DNA
  - Produces messenger RNA (mRNA)
- Translation
  - Is the actual synthesis of a polypeptide, which occurs under the direction of mRNA
  - Occurs on ribosomes

Transcription and Translation

- In prokaryotes transcription and translation occur together

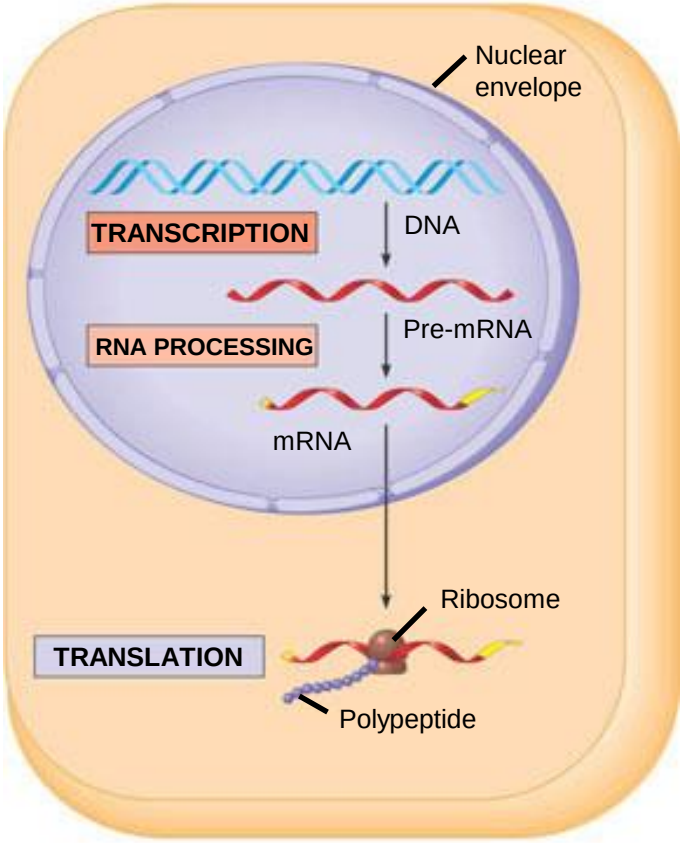


(a) **Prokaryotic cell.** In a cell lacking a nucleus, mRNA produced by transcription is immediately translated without additional processing.

Figure 17.3a

Transcription and Translation

- In a eukaryotic cell the nuclear envelope separates transcription from translation
- Extensive RNA processing occurs in the nucleus



(b) Eukaryotic cell. The nucleus provides a separate compartment for transcription. The original RNA transcript, called pre-mRNA, is processed in various ways before leaving the nucleus as mRNA.

RNA

- RNA is single stranded, not double stranded like DNA
- RNA is short, only 1 gene long, where DNA is very long and contains many genes
- RNA uses the sugar ribose instead of deoxyribose in DNA
- RNA uses the base uracil (U) instead of thymine (T) in DNA.

Type of RNA	Functions
Messenger RNA (mRNA)	Carries information specifying amino acid sequences of proteins from DNA to ribosomes.
Transfer RNA (tRNA)	Serves as adapter molecule in protein synthesis; translates mRNA codons into amino acids.
Ribosomal RNA (rRNA)	Plays catalytic (ribozyme) roles and structural roles in ribosomes.
Primary transcript	Serves as a precursor to mRNA, rRNA, or tRNA, before being processed by splicing or cleavage. Some intron RNA acts as a ribozyme, catalyzing its own splicing.
Small nuclear RNA (snRNA)	Plays structural and catalytic roles in spliceosomes, the complexes of protein and RNA that splice pre-mRNA.

Table 17.1

Types of RNA

The three main types of RNA are:

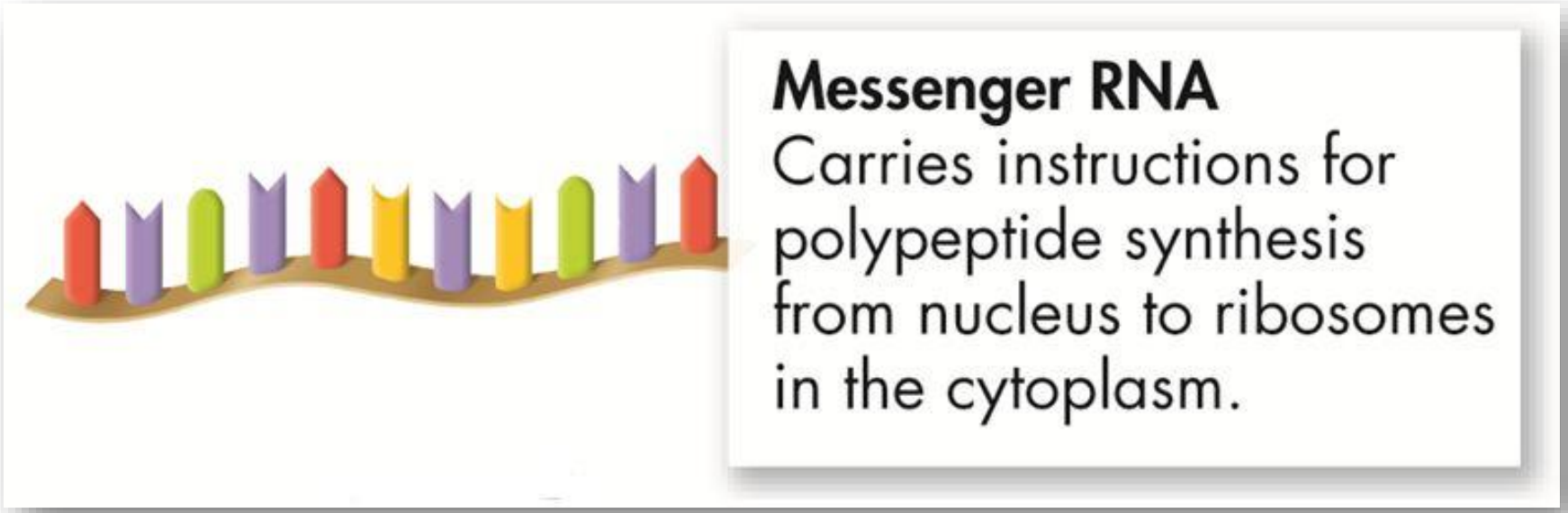
Transfer RNA

Ribosomal RNA

Messenger RNA

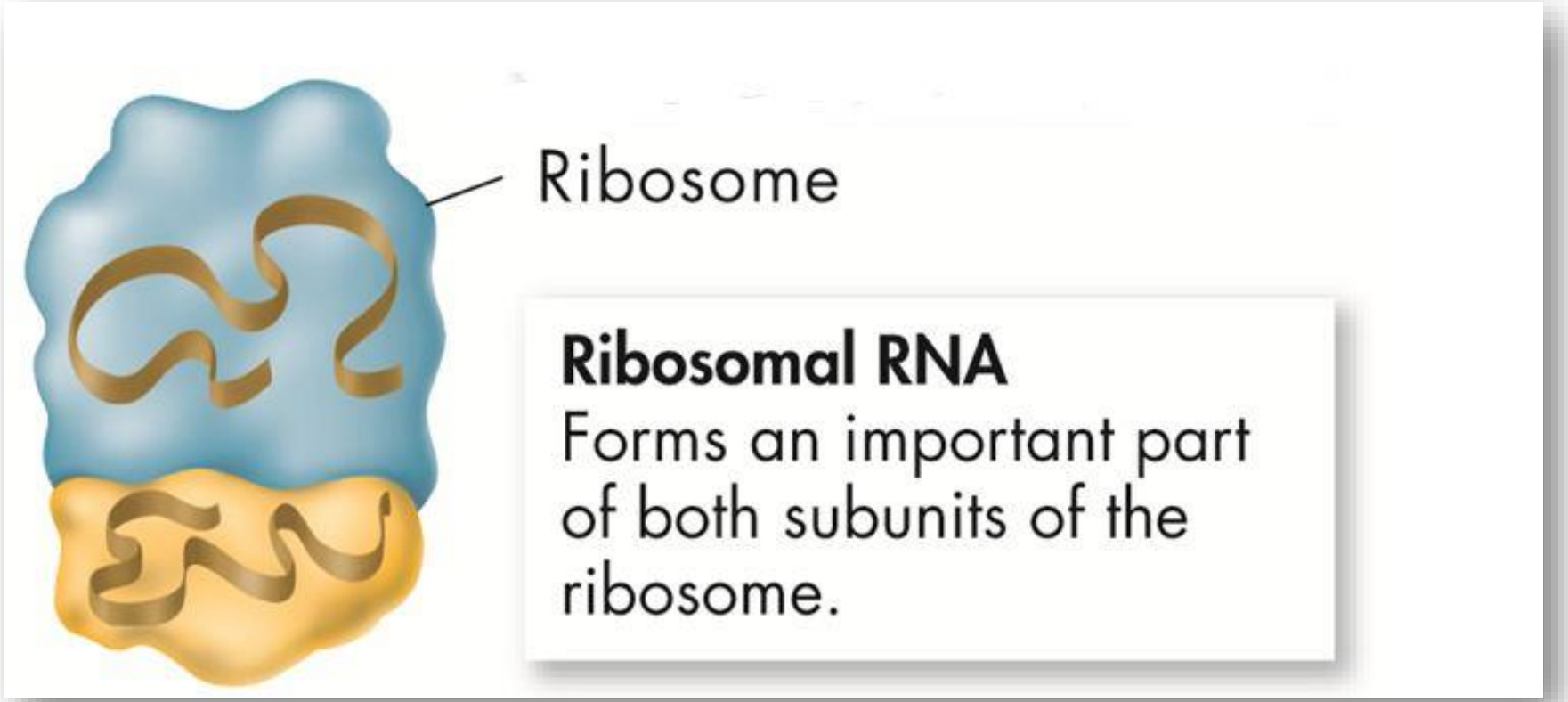
Messenger RNA

- An mRNA molecule is a copy of the portion of DNA that will be used to make a protein.
- After being made in the nucleus, mRNA travels to the cytoplasm, the site of protein synthesis.



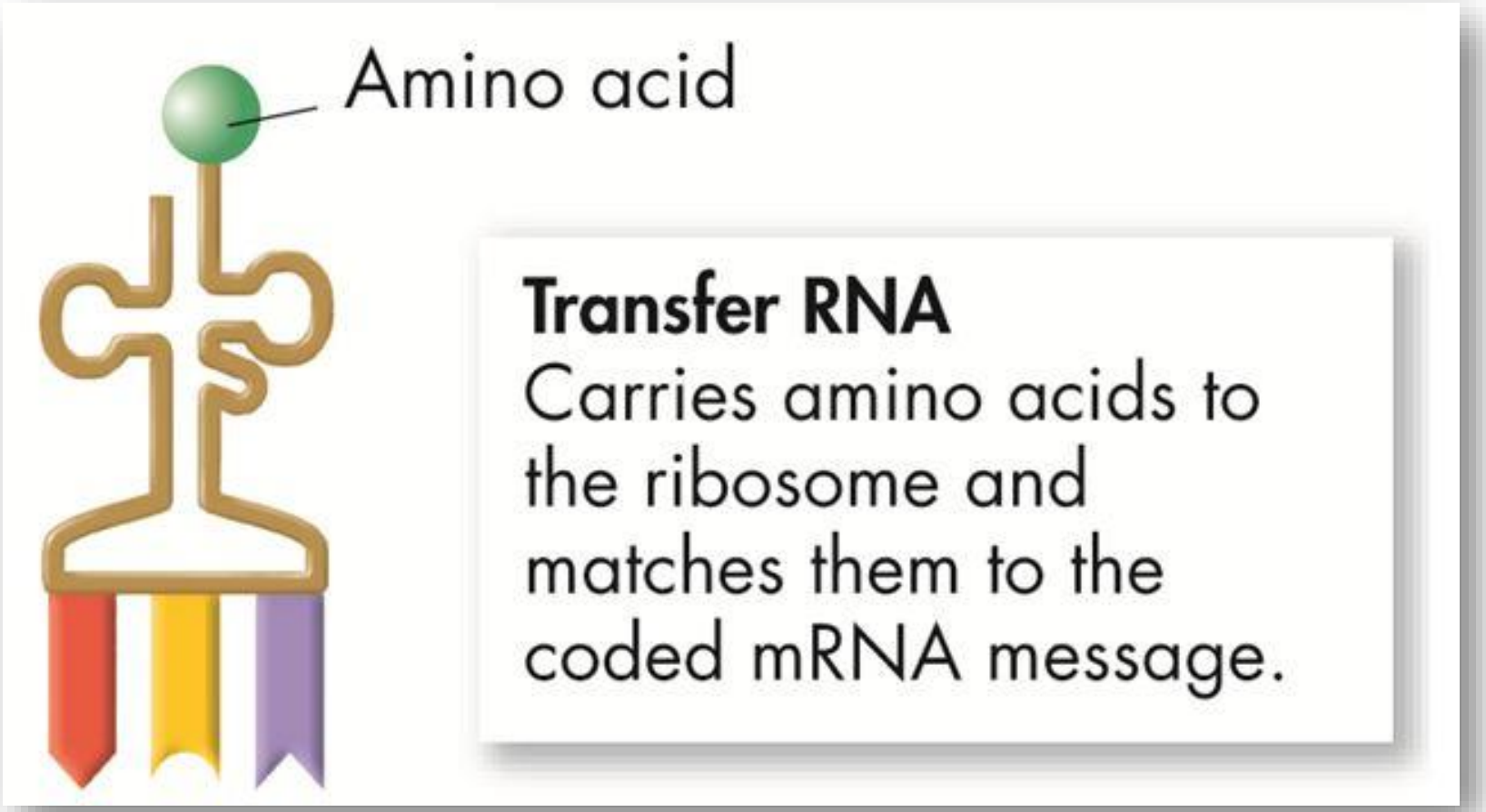
Ribosomal RNA

- Protein synthesis occurs on ribosomes, which are made up of two subunits.
- Both subunits consist of several molecules of ribosomal RNA (rRNA).



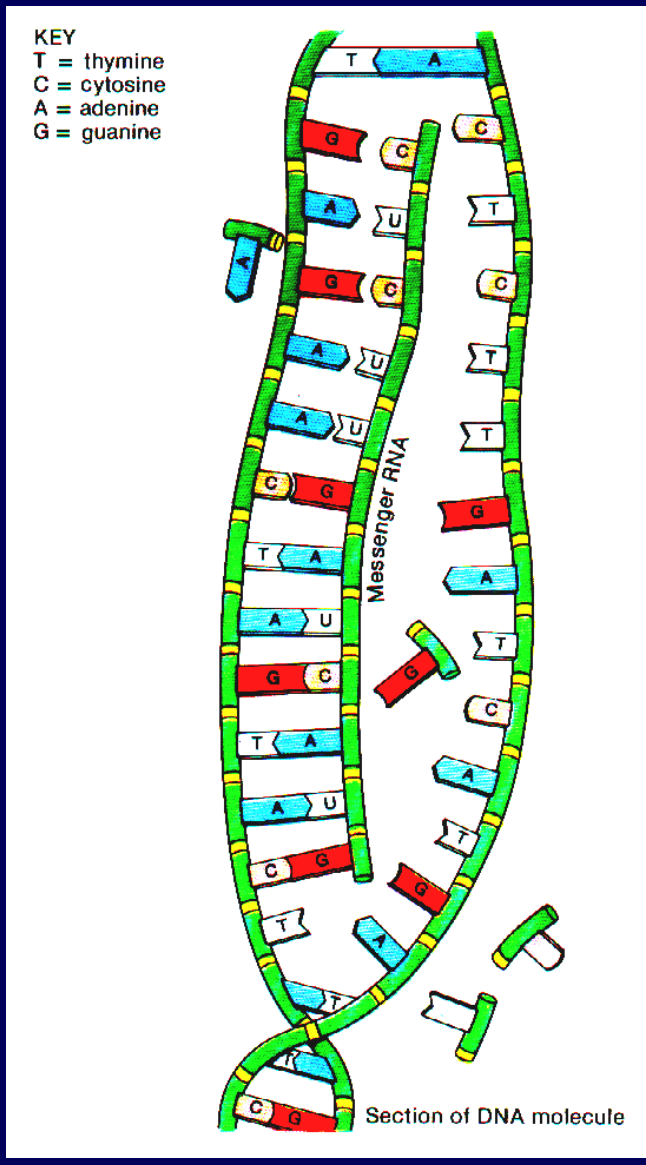
Transfer RNA

During protein synthesis, transfer RNA molecules (tRNA) carry amino acids from the cytoplasm to the mRNA.



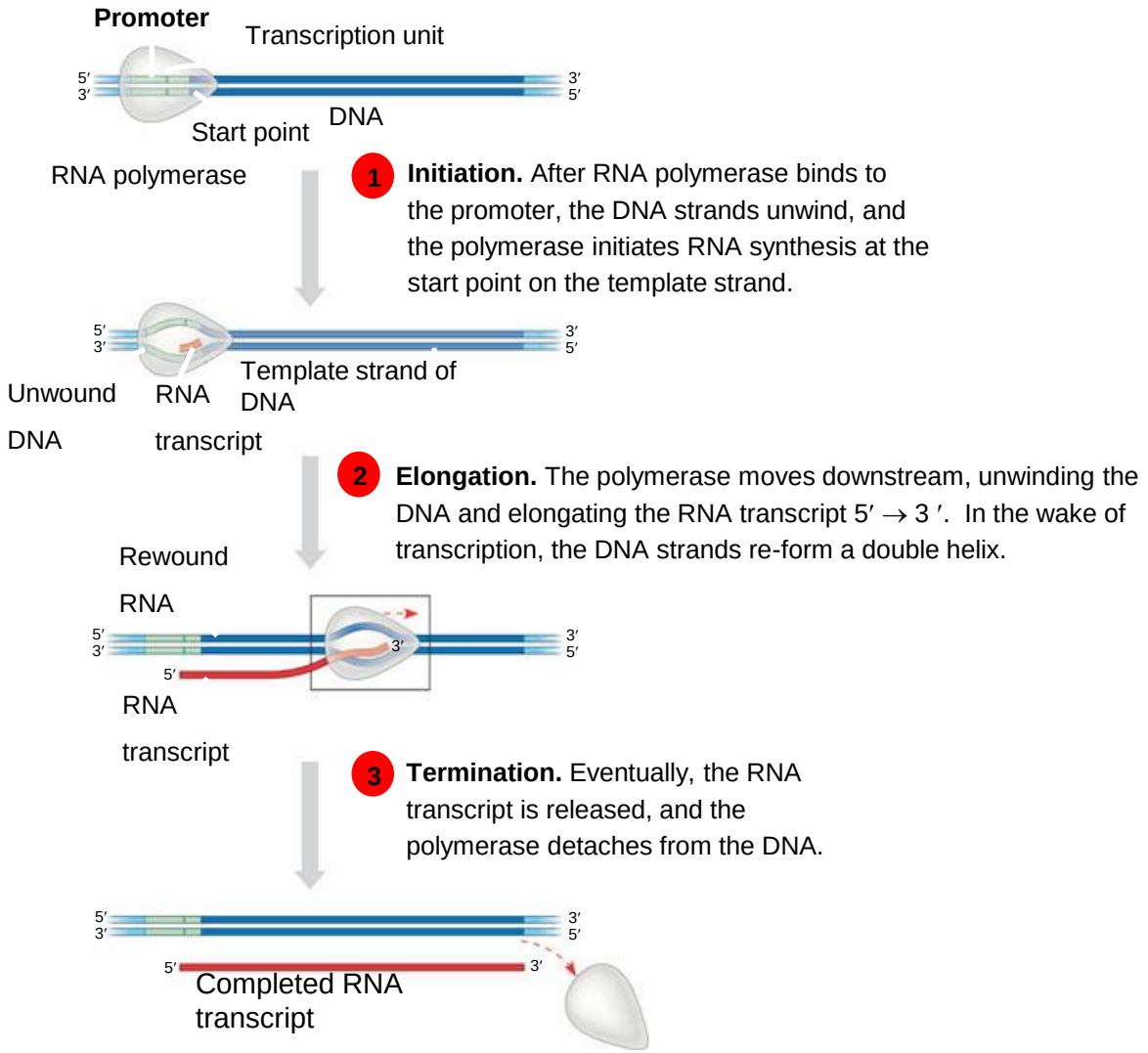
Transcription

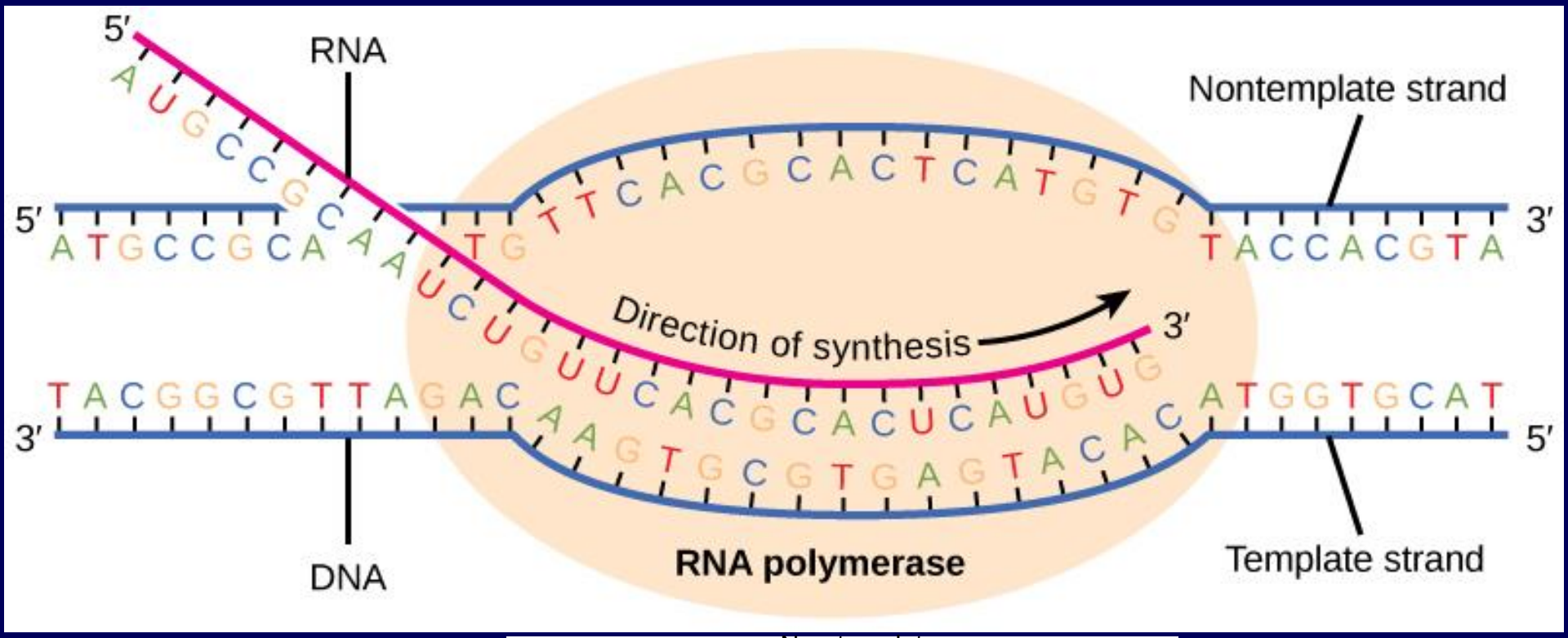
- Transcription is the DNA-directed synthesis of RNA
- RNA synthesis
  - Is catalyzed by RNA polymerase, which pries the DNA strands apart and hooks together the RNA nucleotides
  - Follows the same base-pairing rules as DNA, except that in RNA, uracil substitutes for thymine

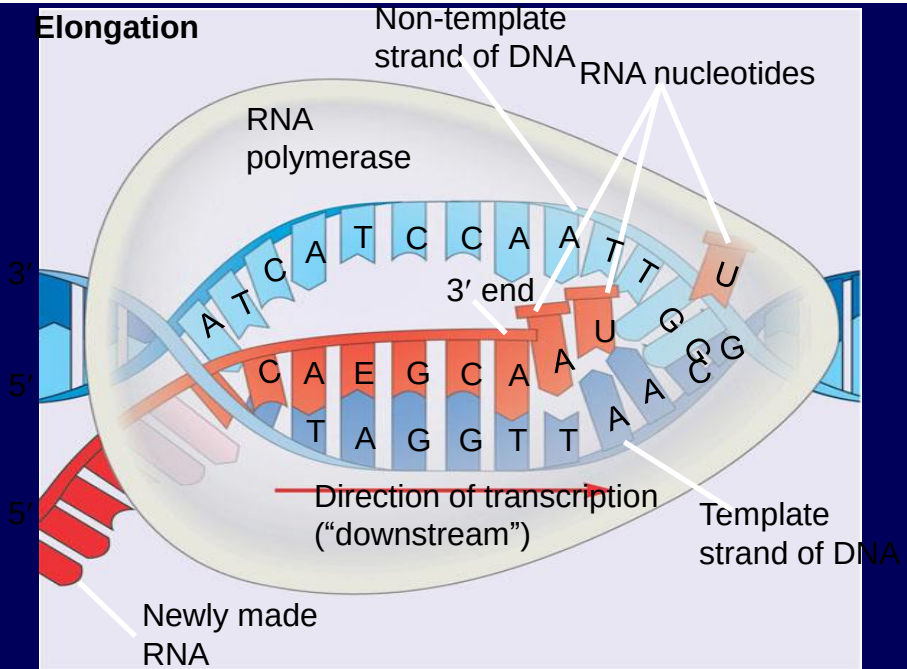


Synthesis of an RNA Transcript

- The stages of transcription are
  - Initiation
  - Elongation
  - Termination

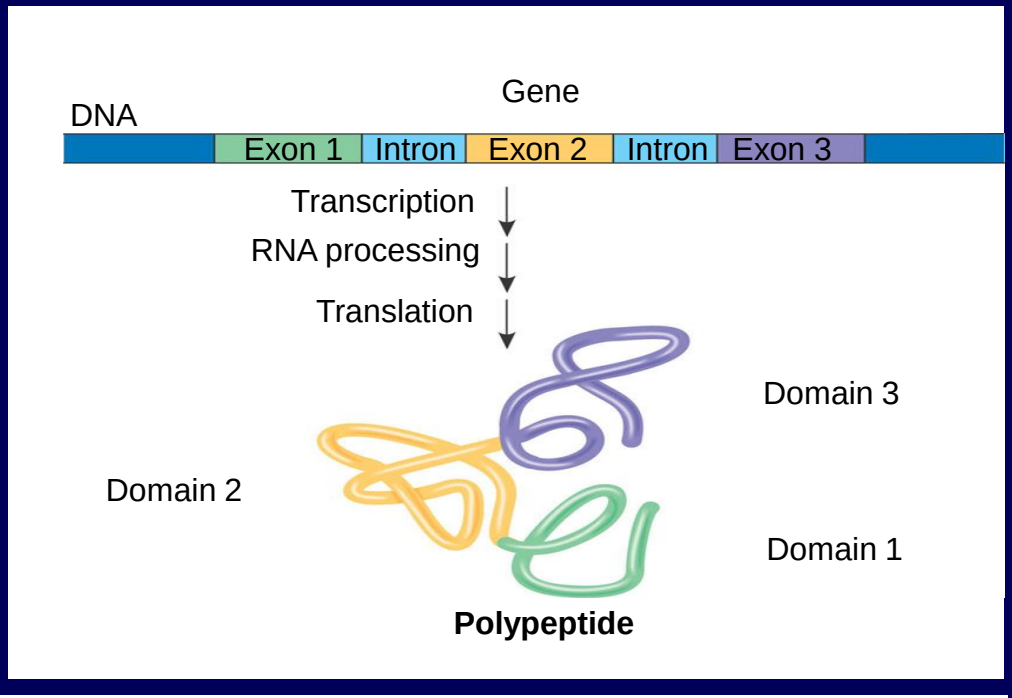


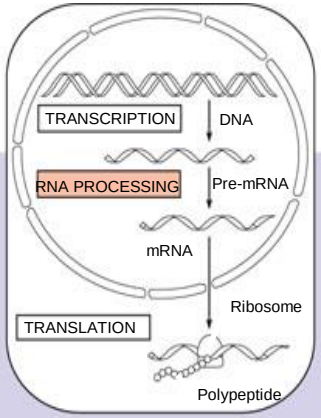

5′
RNA
Nontemplate strand
5′
3′
Direction of synthesis
3′
3′
5′
DNA
RNA polymerase
Template strand


Elongation
Non-template strand of DNA
RNA nucleotides
RNA polymerase
3′
5′
3′ end
5′
Direction of transcription ("downstream")
Template strand of DNA
Newly made RNA

Alteration of mRNA Ends

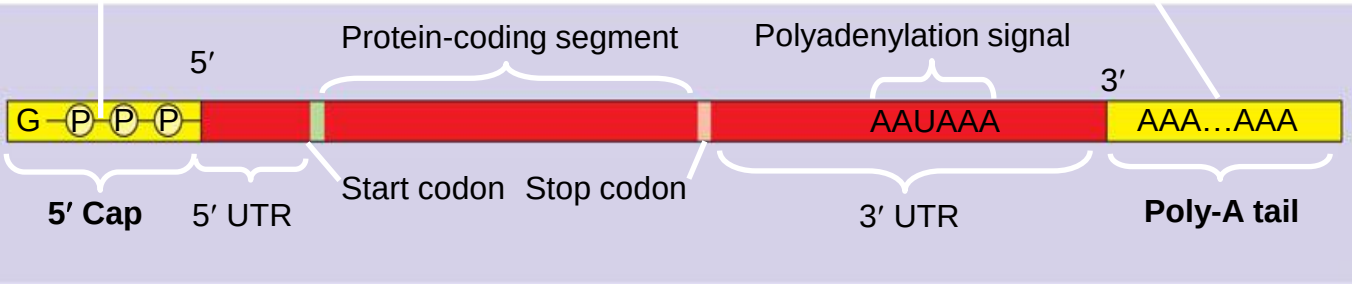
- Each end of a pre-mRNA molecule is modified in a particular way
  - The 5′ end receives a modified nucleotide cap
  - The 3′ end gets a poly-A tail





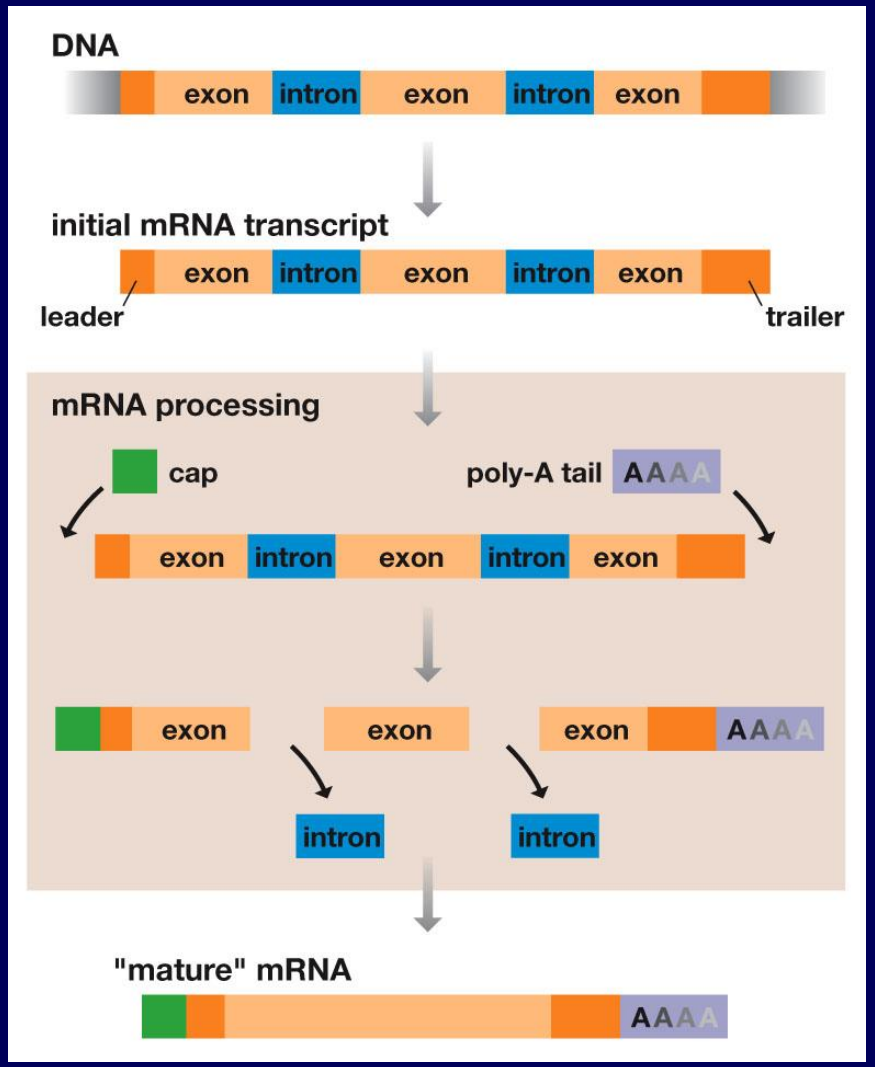
A modified guanine nucleotide added to the 5′ end

50 to 250 adenine nucleotides added to the 3′ end



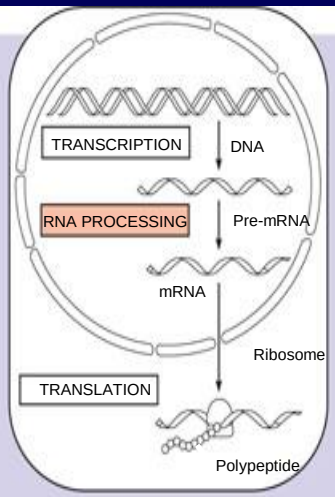
RNA Processing - Splicing

- The original transcript from the DNA is called pre-mRNA.
- It contains transcripts of both introns and exons.
- The introns are removed by a process called splicing to produce messenger RNA (mRNA)



RNA Processing - Splicing

- Ribozymes are catalytic RNA molecules that function as enzymes and can splice RNA
- RNA splicing removes introns and joins exons



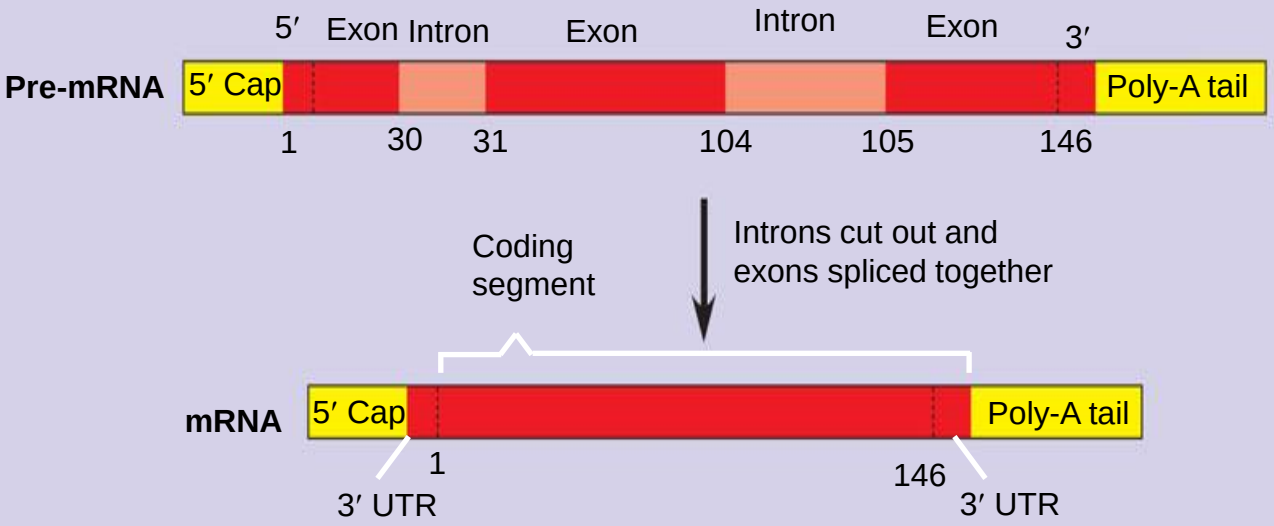
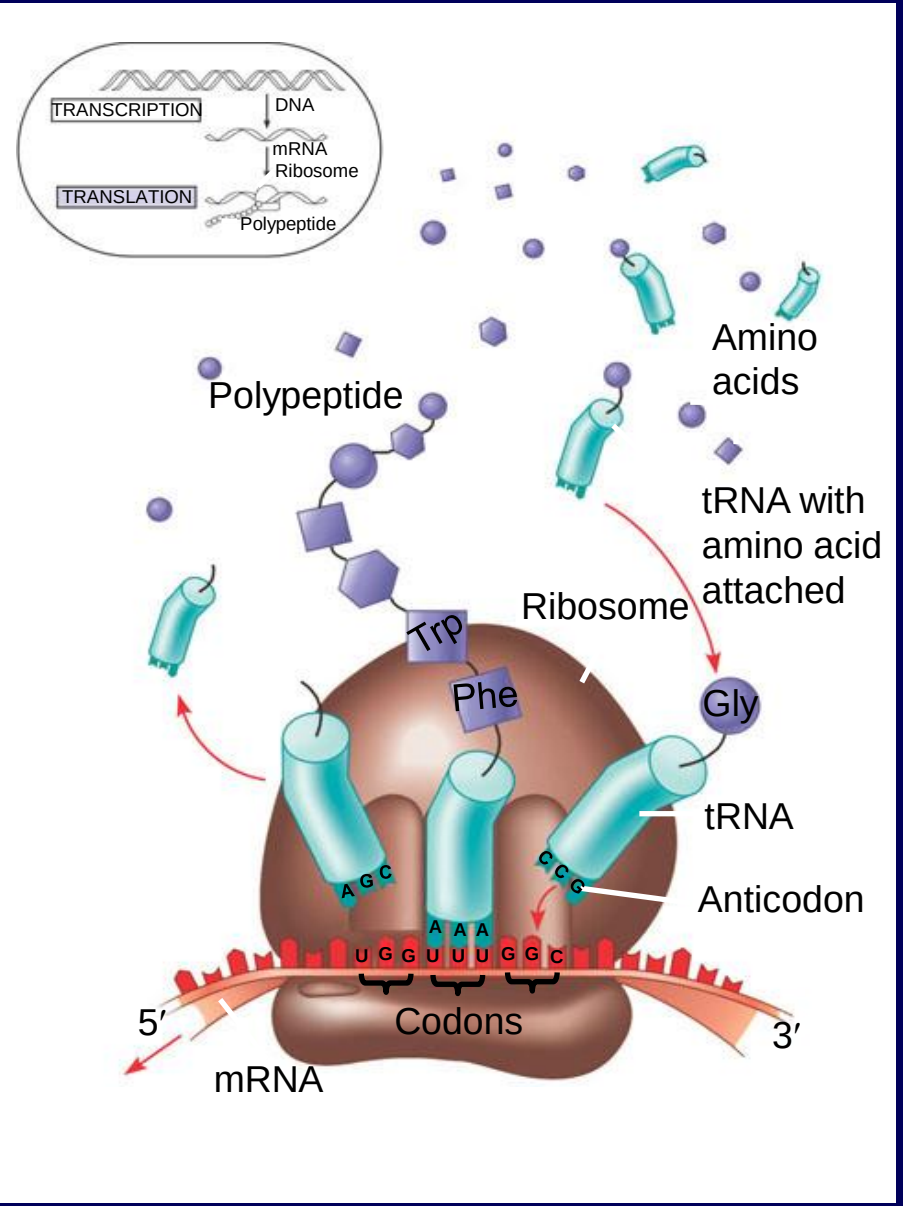


Figure 17.10

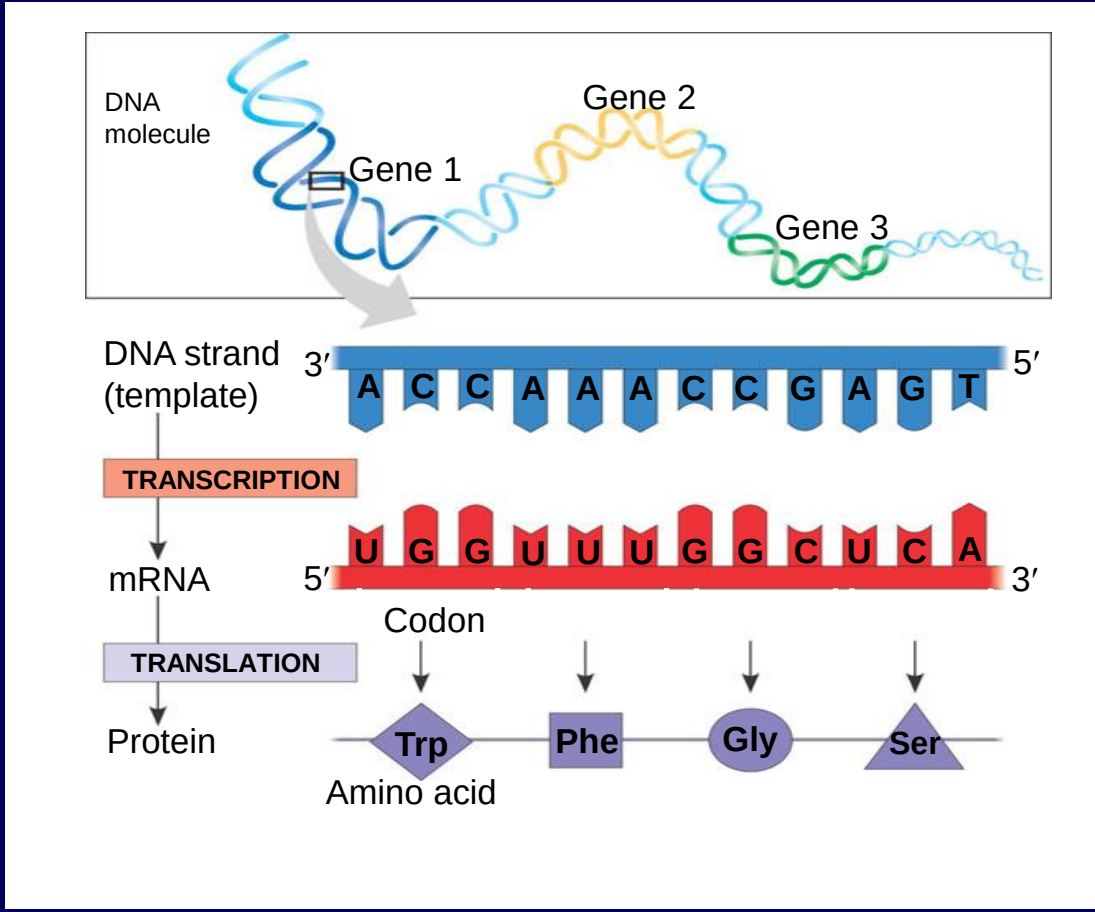
Translation

- Translation is the RNA-directed synthesis of a polypeptide
- Translation involves
  - mRNA
  - Ribosomes - Ribosomal RNA
  - Transfer RNA
  - Genetic coding - codons



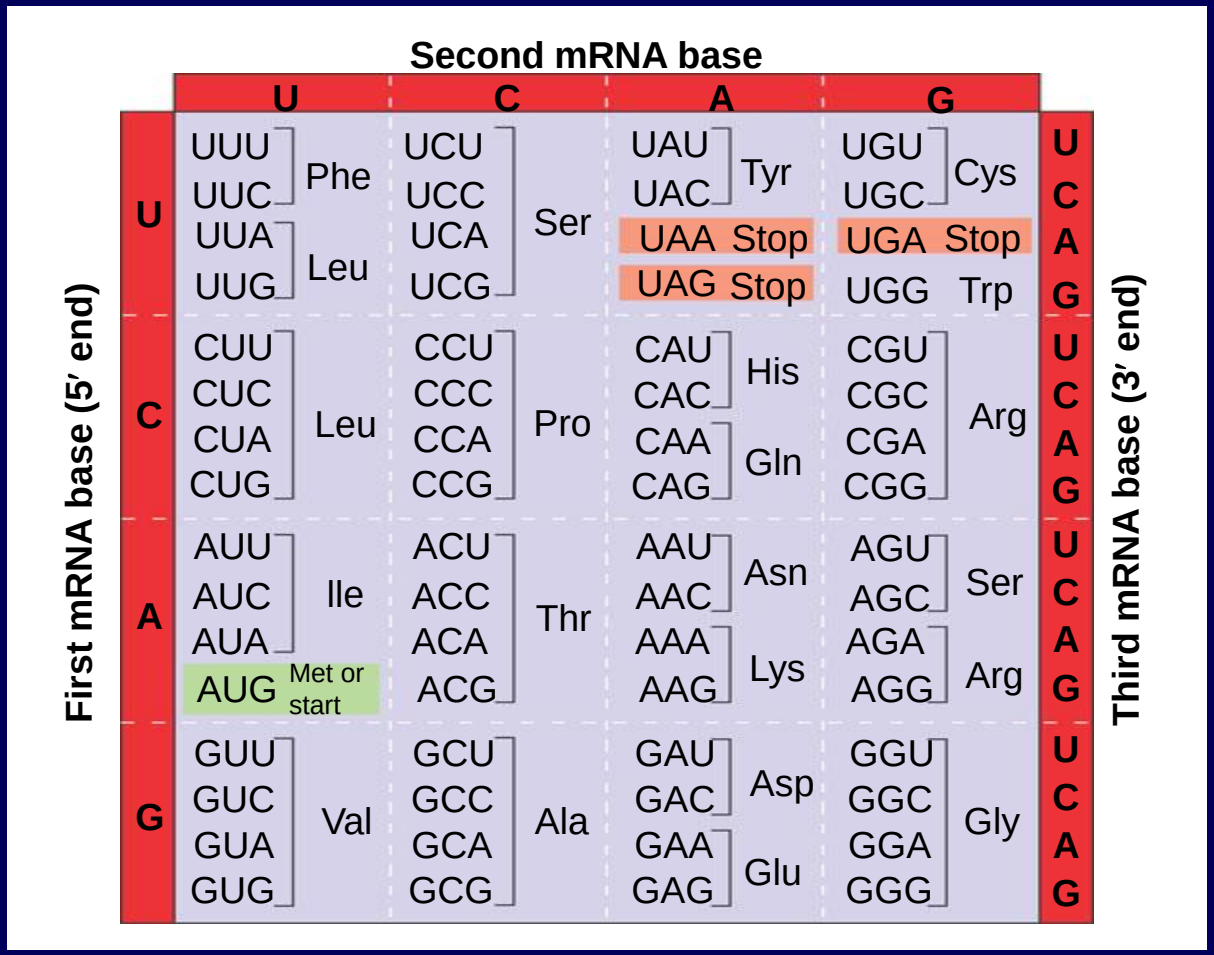
The Genetic Code

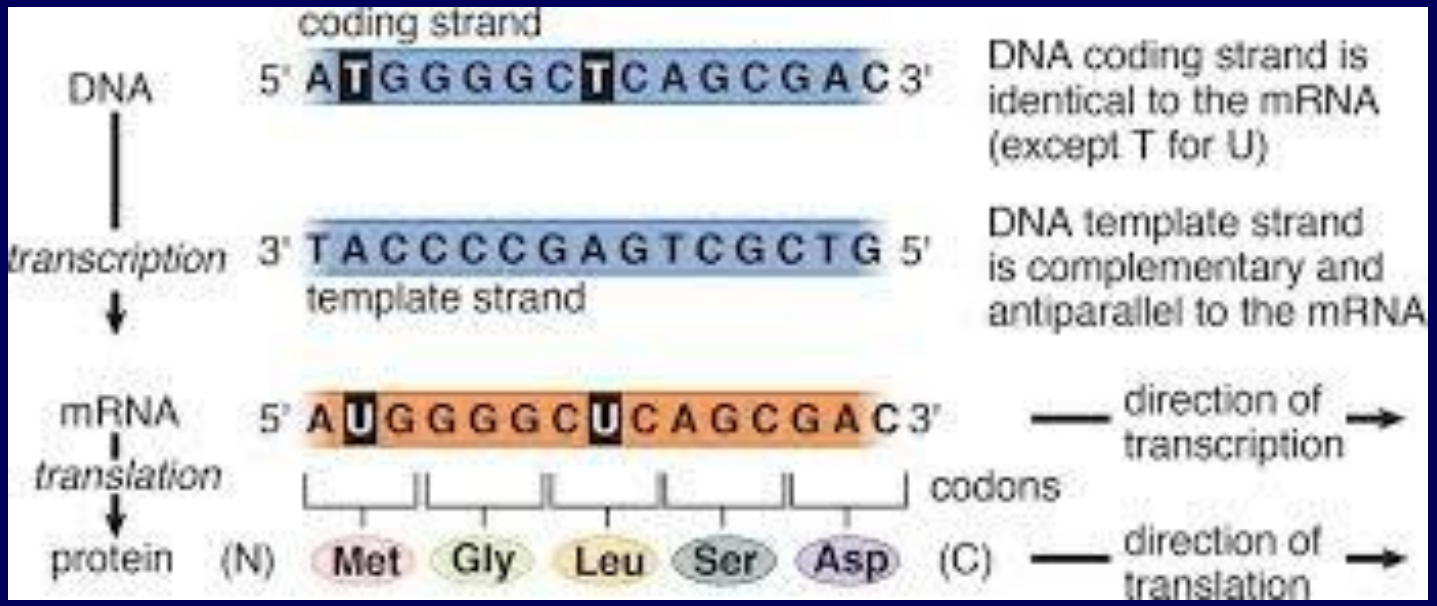
- Genetic information is encoded as a sequence of nonoverlapping base triplets, or codons
- The gene determines the sequence of bases along the length of an mRNA molecule



The Genetic Code

- A codon in messenger RNA is either translated into an amino acid or serves as a translational start/stop signal

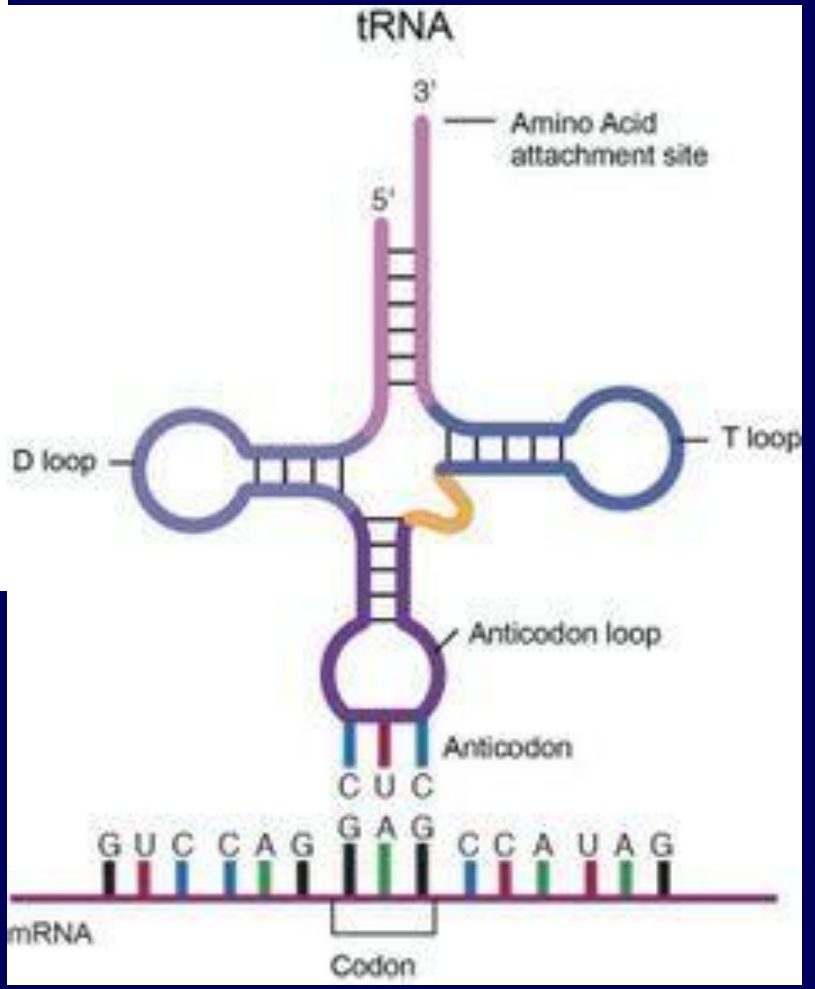




- Codons: 3 base code for the production of a specific amino acid
- Since there are 4 bases and 3 positions in each codon, there are 4 x 4 x 4 = 64 possible codons
- 64 codons but only 20 amino acids, therefore most have more than 1 codon
- 3 of the 64 codons are used as STOP signals; they are found at the end of every gene and mark the end of the protein

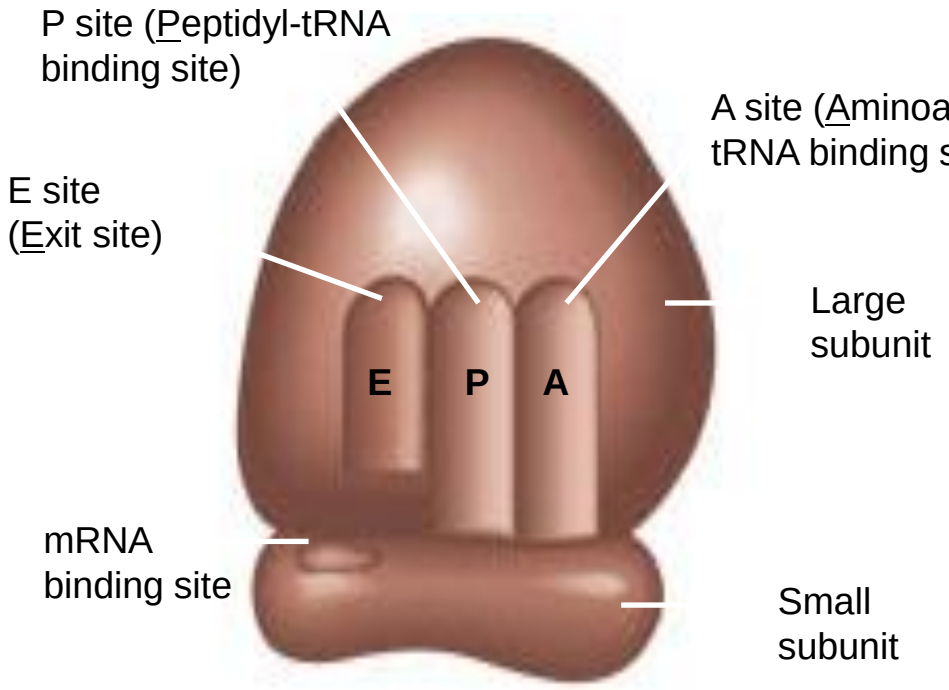
Transfer RNA

- Consists of a single RNA strand that is only about 80 nucleotides long
- Each carries a specific amino acid on one end and has an anticodon on the other end
- A special group of enzymes pairs up the proper tRNA molecules with their corresponding amino acids.
- tRNA brings the amino acids to the ribosomes,



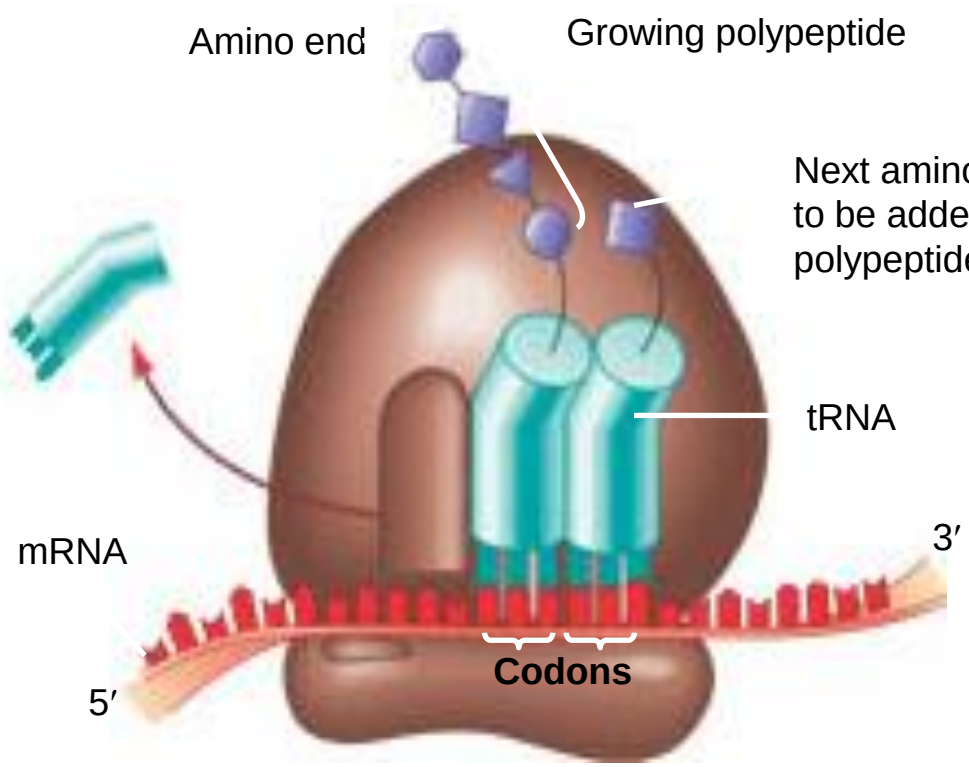
Ribosome

- The ribosome has three binding sites for tRNA
  - The P site
  - The A site
  - The E site



(b) Schematic model showing binding sites. A ribosome has an mRNA binding site and three tRNA binding sites, known as the A, P, and E sites. This schematic ribosome will appear in later diagrams.

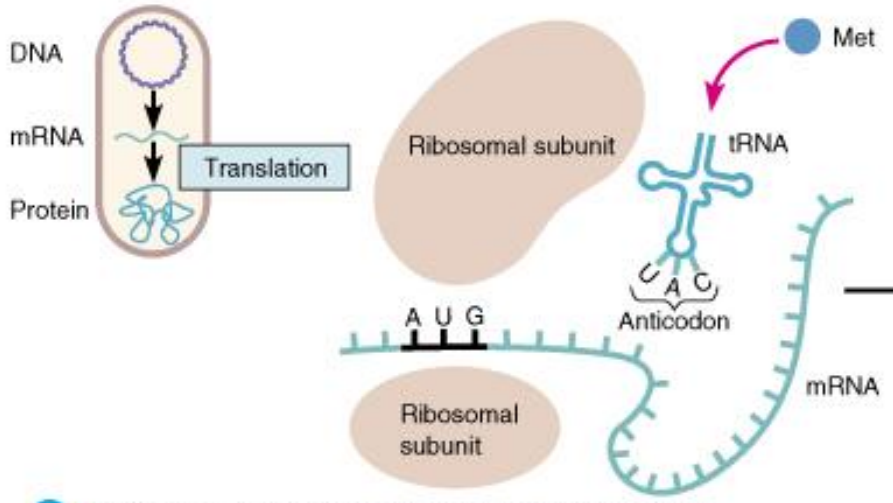
Building a Polypeptide



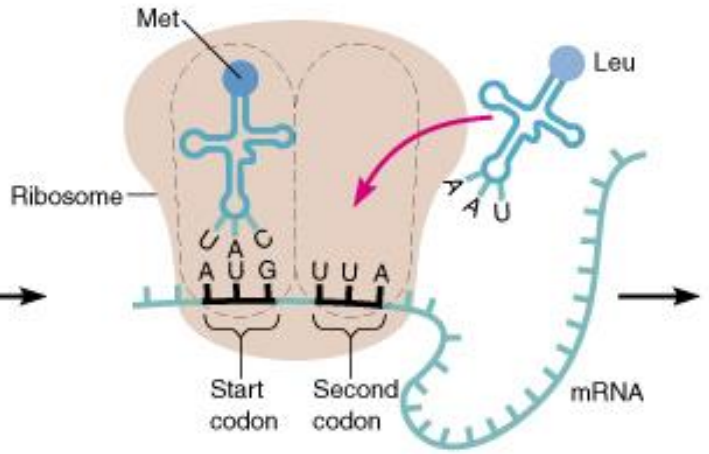
(c) **Schematic model with mRNA and tRNA.** A tRNA fits into a binding site when its anticodon base-pairs with an mRNA codon. The P site holds the tRNA attached to the growing polypeptide. The A site holds the tRNA carrying the next amino acid to be added to the polypeptide chain. Discharged tRNA leaves via the E site.

Building a Polypeptide

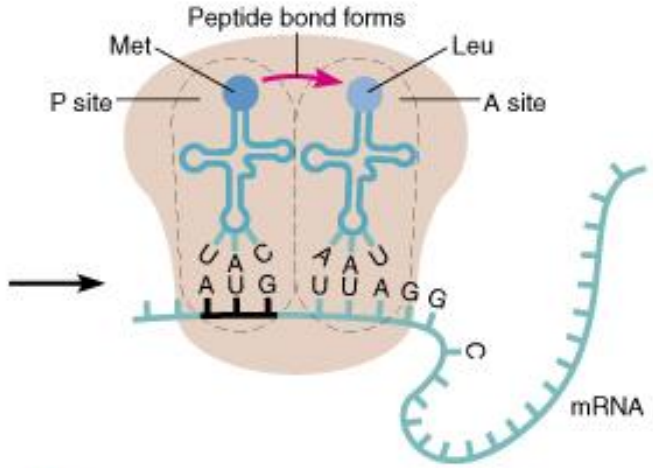
- We can divide translation into three stages
  - Initiation
  - Elongation
  - Termination
- The AUG start codon is recognized by methionyl-tRNA or Met
- Once the start codon has been identified, the ribosome incorporates amino acids into a polypeptide chain
- RNA is decoded by tRNA (transfer RNA) molecules, which each transport specific amino acids to the growing chain
- Translation ends when a stop codon (UAA, UAG, UGA) is reached



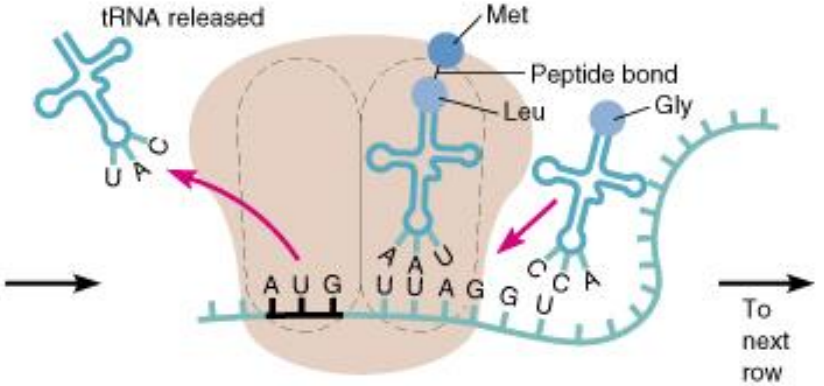
1 Components needed to begin translation come together.



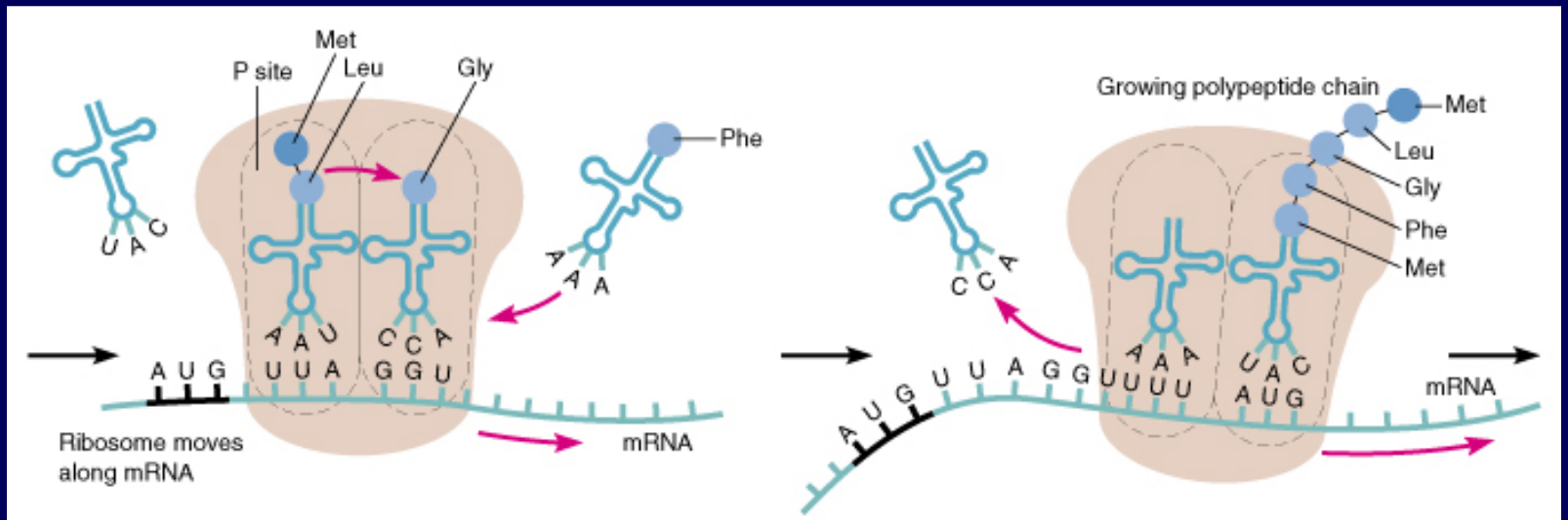
2 On the assembled ribosome, a tRNA carrying the first amino acid is paired with the start codon on the mRNA. A tRNA carrying the second amino acid approaches.



3 The place on the ribosome where the first tRNA sits is called the P site. In the A site next to it, the second codon of the mRNA pairs with a tRNA carrying the second amino acid.

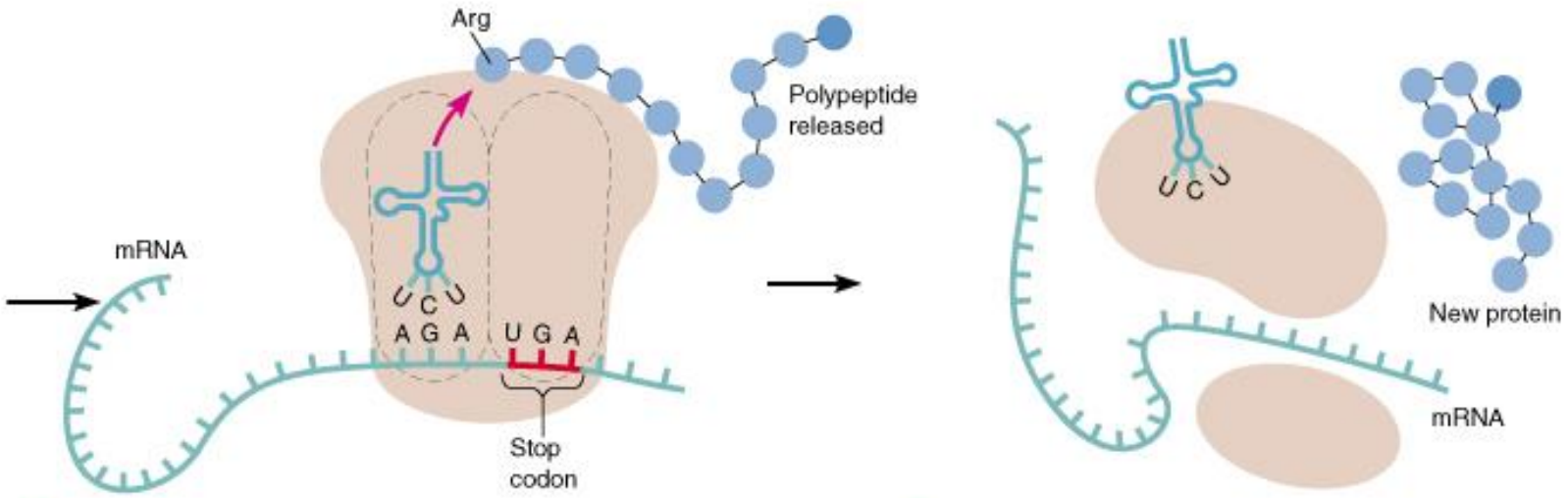


4 The first amino acid joins to the second by a peptide bond, and the first tRNA is released.



5 The ribosome moves along the mRNA until the second tRNA is in the P site, and the process continues.

6 The ribosome continues to move along the mRNA, and new amino acids are added to the polypeptide.

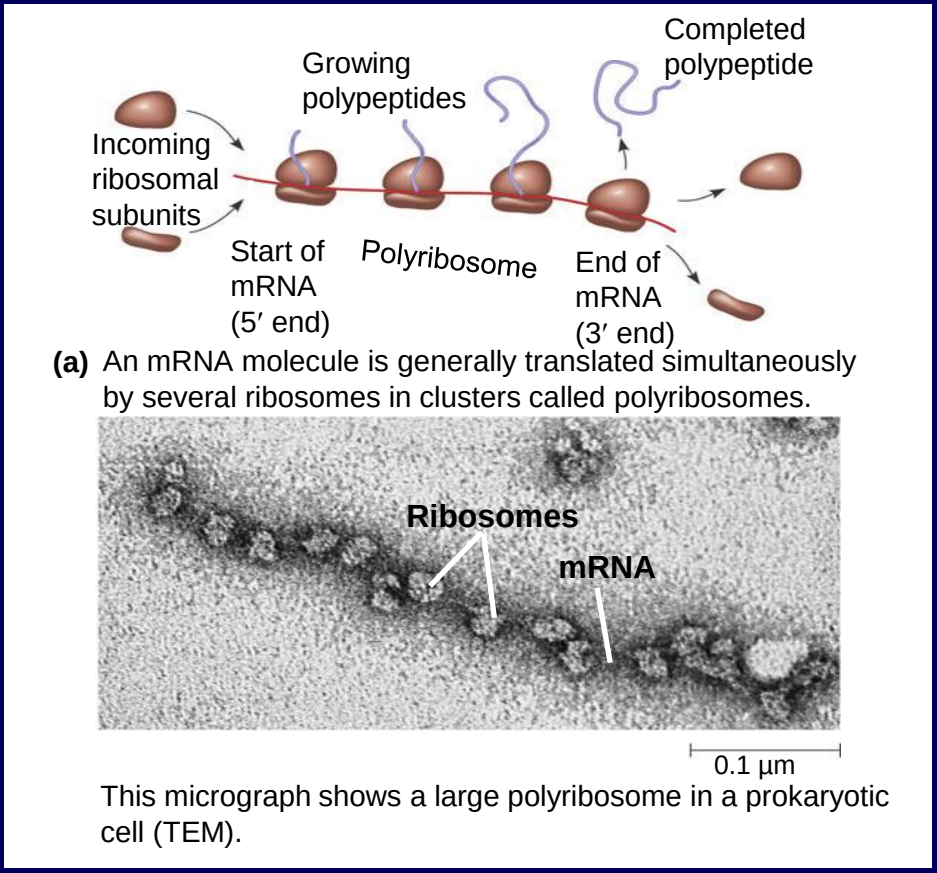


7 When the ribosome reaches a stop codon, the polypeptide is released.

8 Finally, the last tRNA is released, and the ribosome comes apart. The released polypeptide forms a new protein.

Polyribosomes

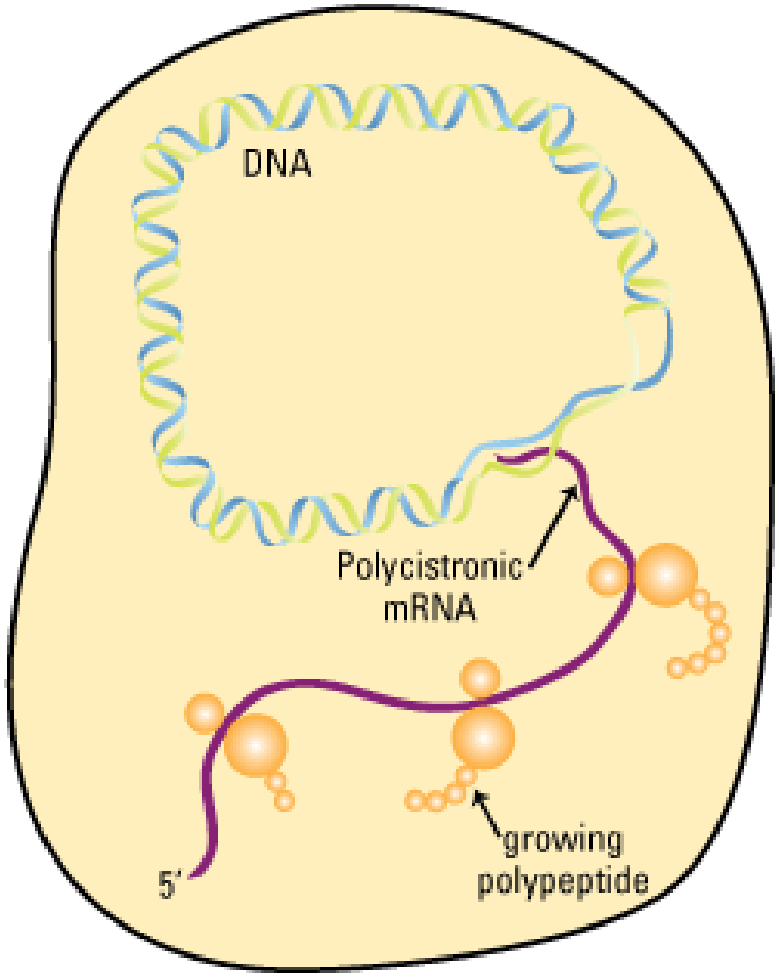
- A number of ribosomes can translate a single mRNA molecule simultaneously forming a polyribosome
- Polyribosomes enable a cell to make many copies of a polypeptide very quickly



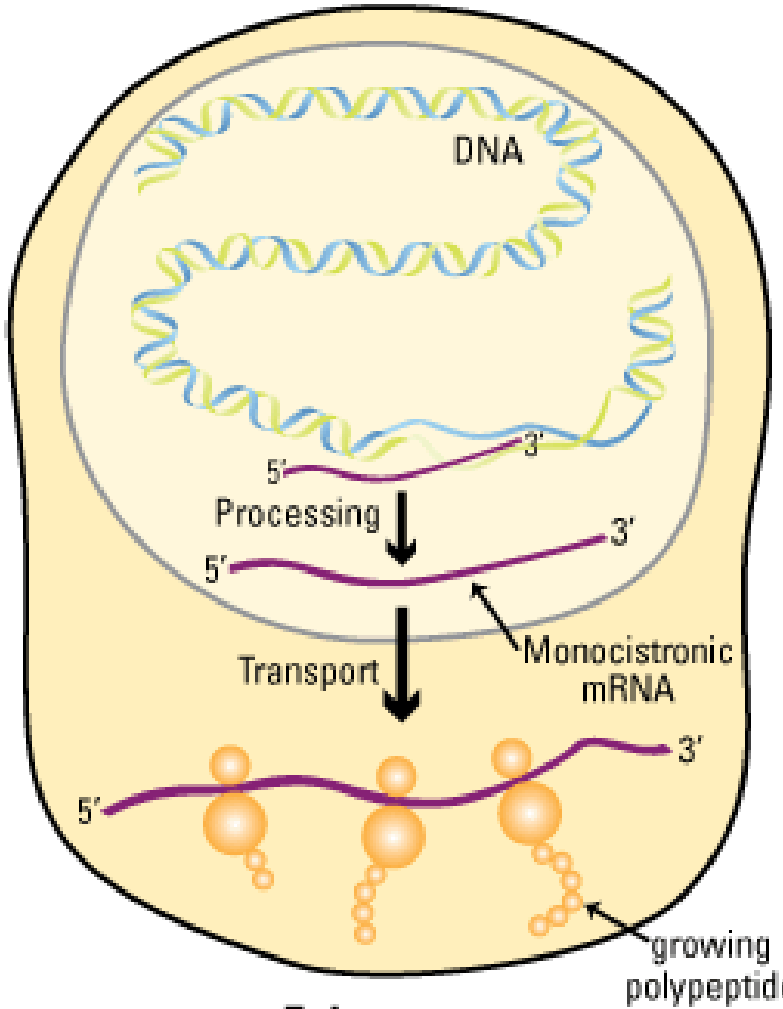
(a) An mRNA molecule is generally translated simultaneously by several ribosomes in clusters called polyribosomes.

This micrograph shows a large polyribosome in a prokaryotic cell (TEM).

Comparing Gene Expression In Prokaryotes And Eukaryotes

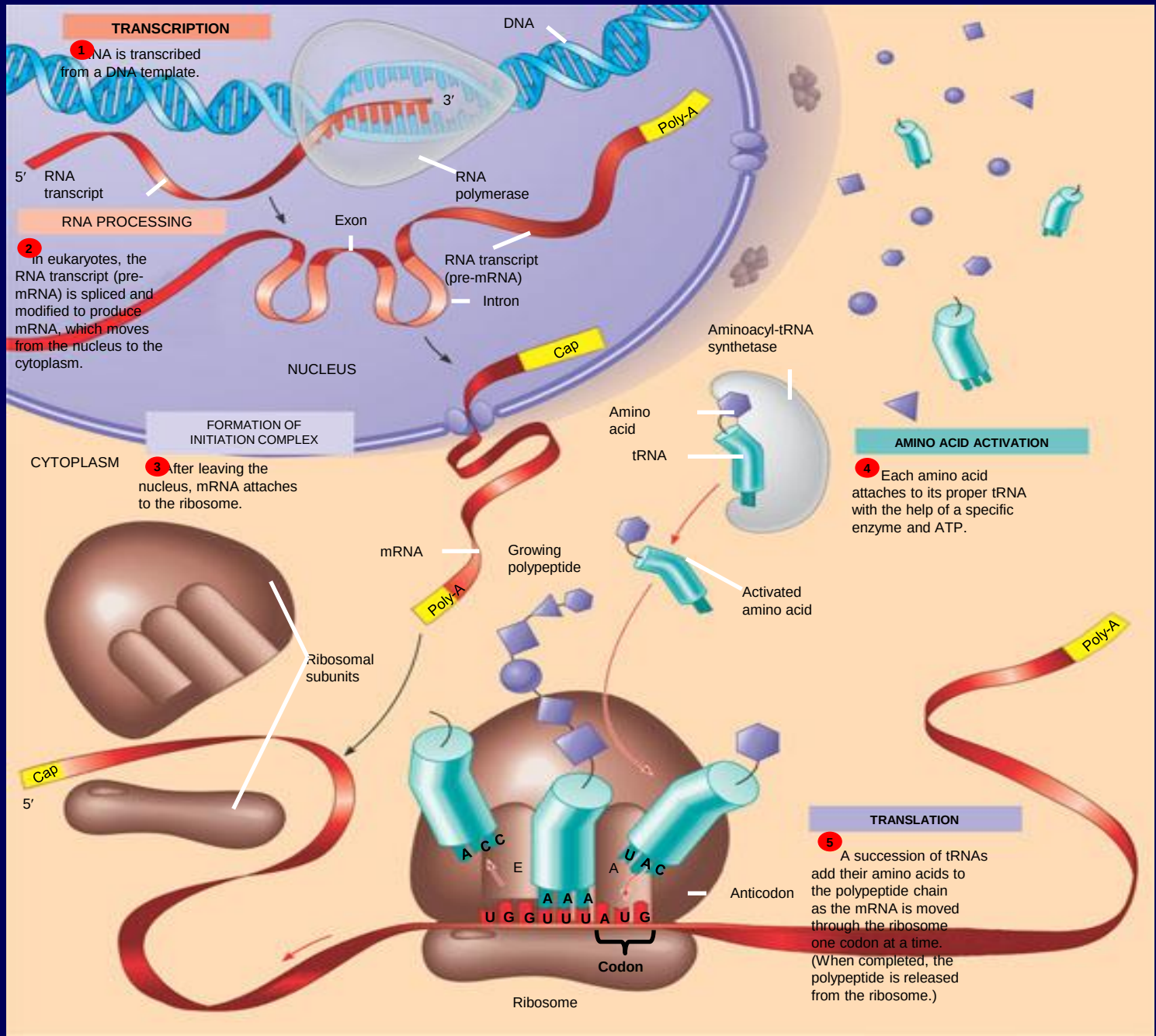


Prokaryotes



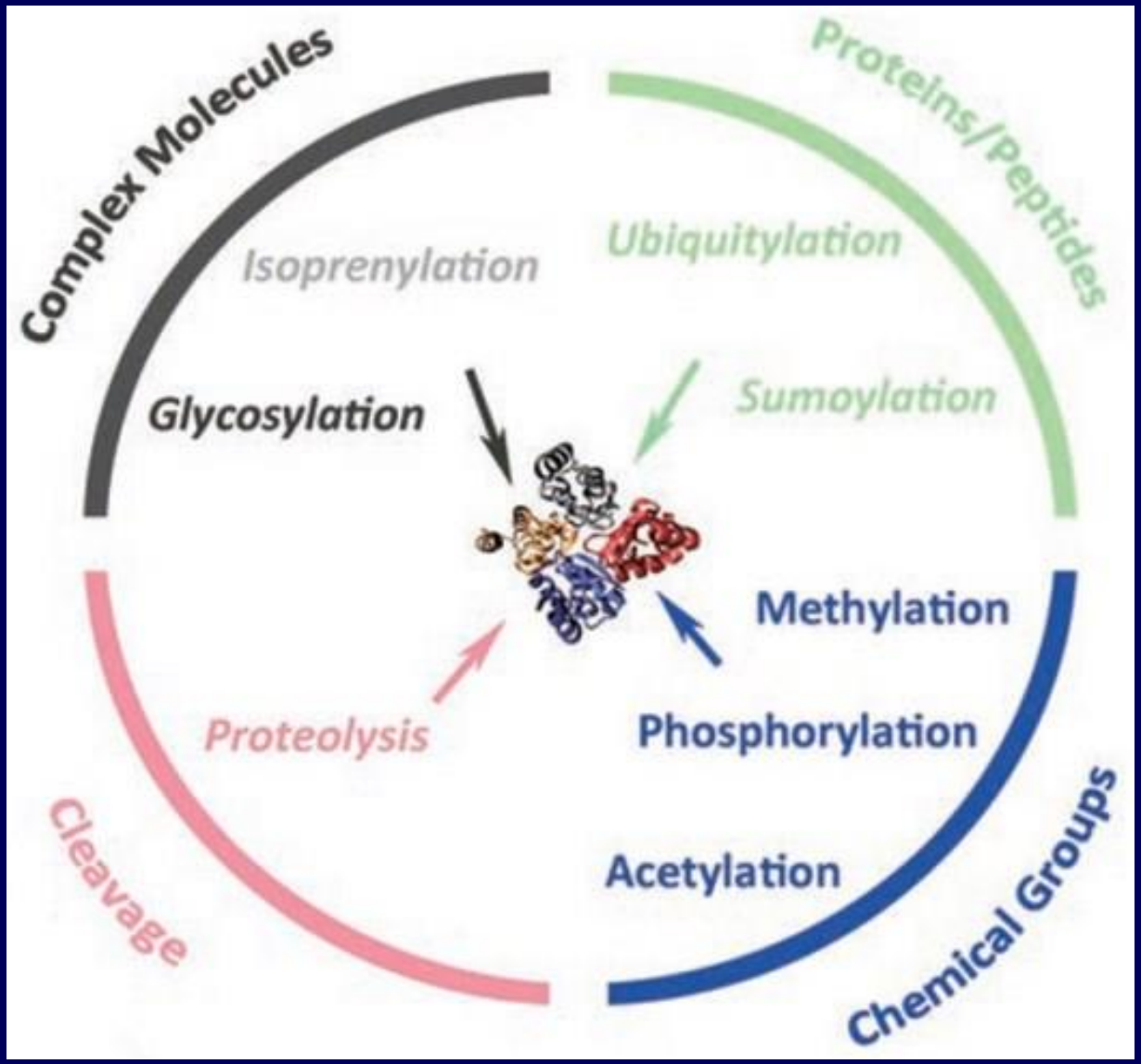
Eukaryotes

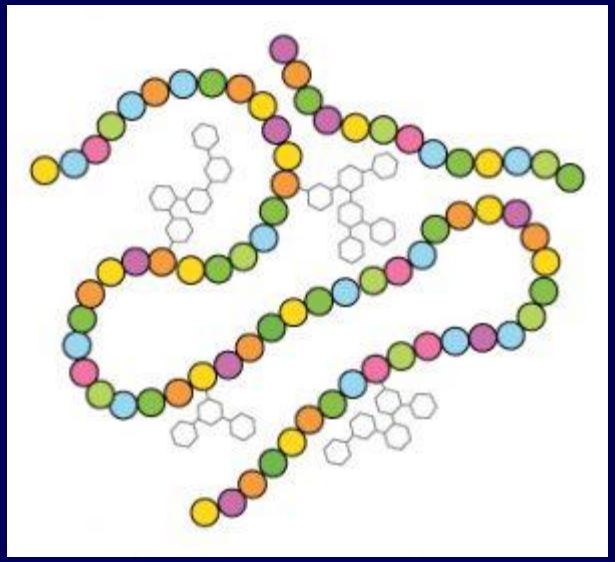
A summary of transcription and translation in a eukaryotic cell

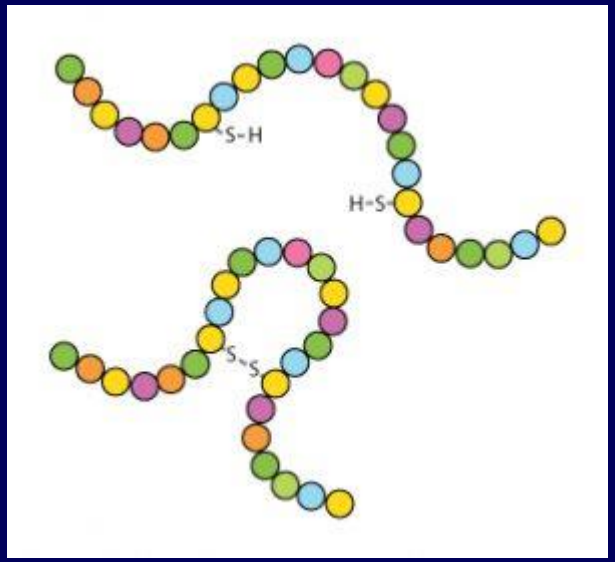


Post-translation

- The new polypeptide is now floating loose in the cytoplasm if translated by a free ribosome.
- Polypeptides fold spontaneously into their active configuration, and they spontaneously join with other polypeptides to form the final proteins.
- Often translation is not sufficient to make a functional protein, polypeptide chains are modified after translation
- Sometimes other molecules are also attached to the polypeptides: sugars, lipids, phosphates, etc. All of these have special purposes for protein function.


Complex Molecules
Proteins/Peptides
Isoprenylation
Ubiquitylation
Glycosylation
Sumoylation
Methylation
Proteolysis
Phosphorylation
Cleavage
Acetylation
Chemical Groups




S-H
H-S
S-S