Chapter 17

From Gene to Protein

Transcription & translation is important

PowerPoint Lectures for
Biology, Seventh Edition
Neil Campbell and Jane Reece

Lectures by Chris Romero

- Overview: The Flow of Genetic Information
- The information content of DNA
  - Is in the form of specific sequences of nucleotides along the DNA strands

- The DNA inherited by an organism
  - Leads to specific traits by dictating the synthesis of proteins
- The process by which DNA directs protein synthesis, gene expression
  - Includes two stages, called transcription and translation

- The ribosome
  - Is part of the cellular machinery for translation, polypeptide synthesis

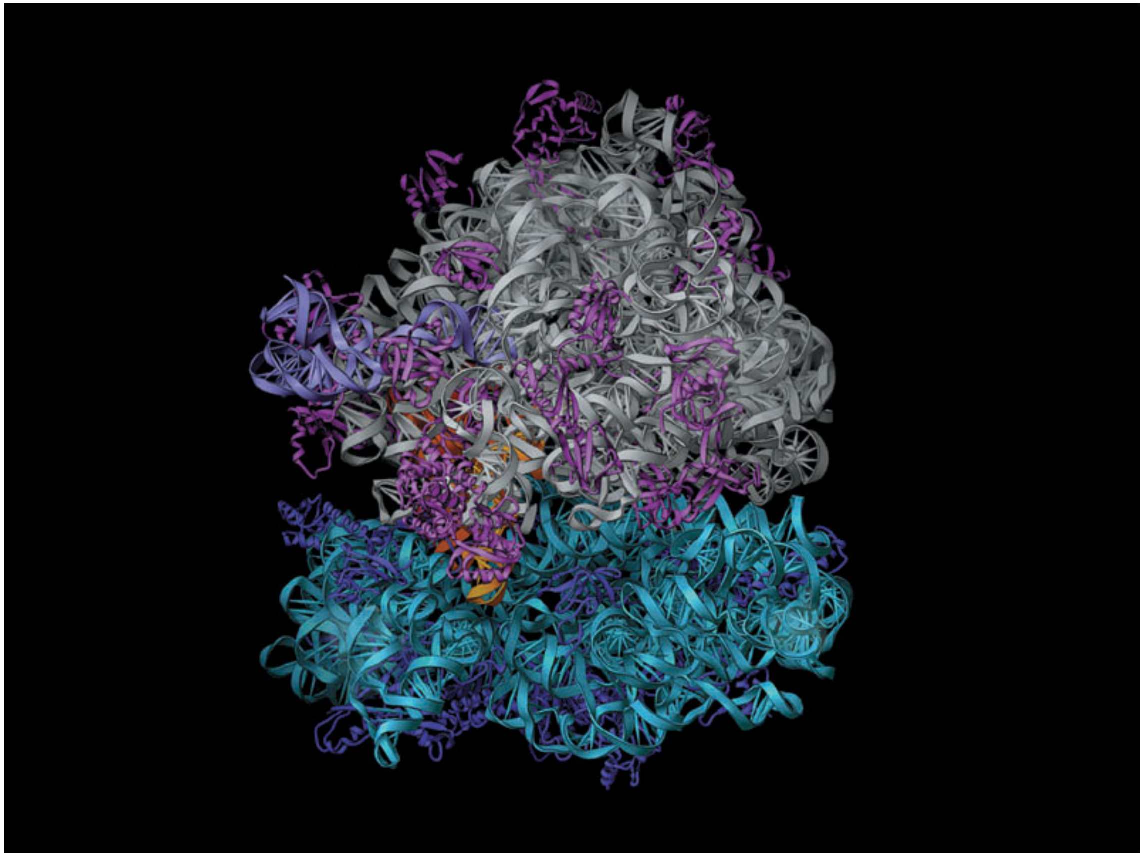


Figure 17.1

- Concept 17.1: Genes specify proteins via transcription and translation

Evidence from the Study of Metabolic Defects

- In 1909, British physician Archibald Garrod
  - Was the first to suggest that genes dictate phenotypes through enzymes that catalyze specific chemical reactions in the cell

Nutritional Mutants in Neurospora: *Scientific Inquiry*

- Beadle and Tatum causes bread mold to mutate with X-rays
  - Creating mutants that could not survive on minimal medium

- Using genetic crosses
  - They determined that their mutants fell into three classes, each mutated in a different gene

EXPERIMENT Working with the mold *Neurospora crassa*, George Beadle and Edward Tatum had isolated mutants requiring arginine in their growth medium and had shown genetically that these mutants fell into three classes, each defective in a different gene. From other considerations, they suspected that the metabolic pathway of arginine biosynthesis included the precursors ornithine and citrulline. Their most famous experiment, shown here, tested both their one gene–one enzyme hypothesis and their postulated arginine pathway. In this experiment, they grew their three classes of mutants under the four different conditions shown in the Results section below.

RESULTS The wild-type strain required only the minimal medium for growth. The three classes of mutants had different growth requirements

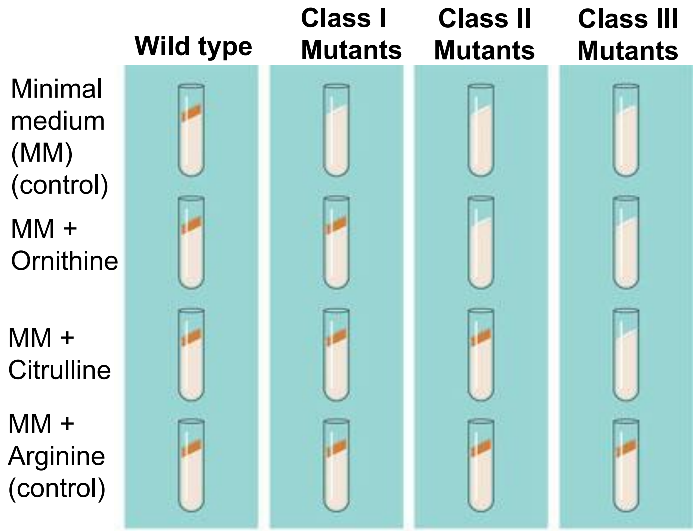
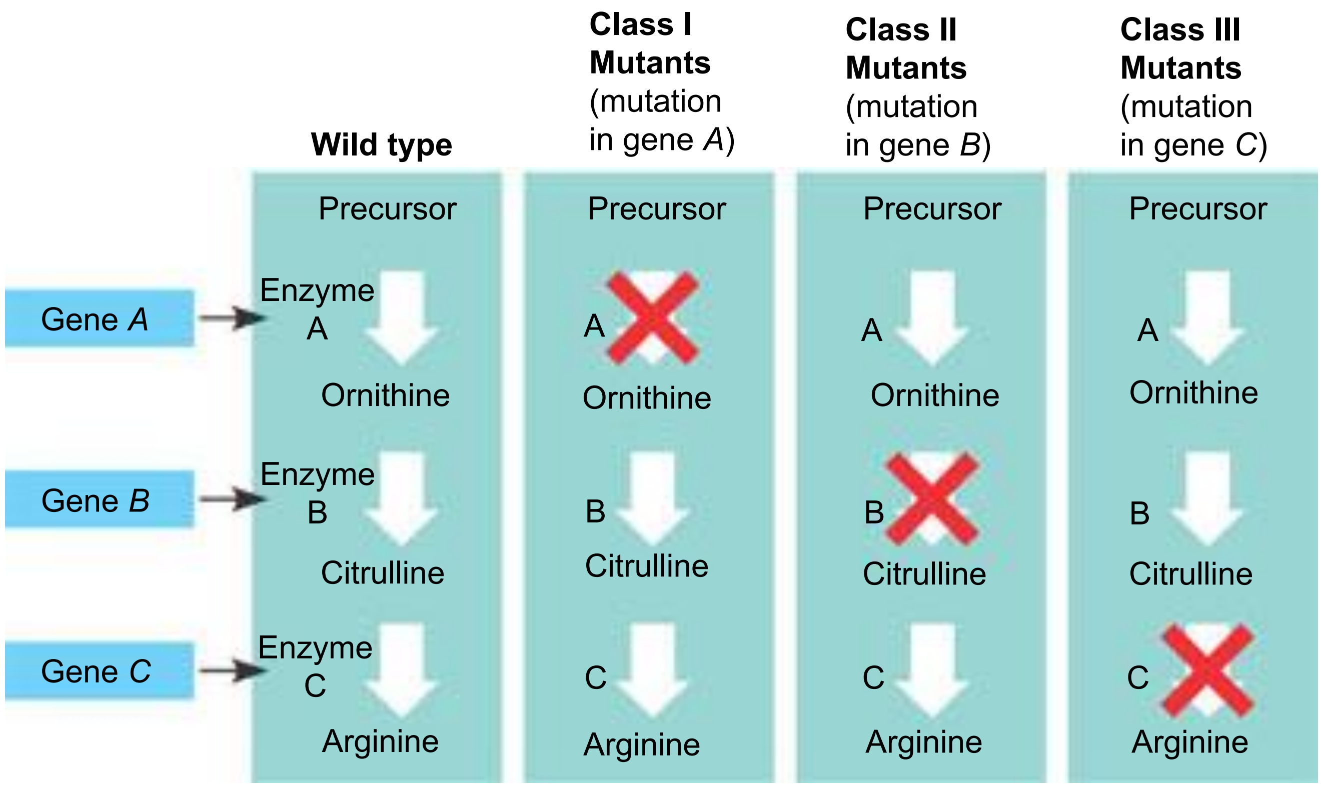


Figure 17.2

CONCLUSION

From the growth patterns of the mutants, Beadle and Tatum deduced that each mutant was unable to carry out one step in the pathway for synthesizing arginine, presumably because it lacked the necessary enzyme. Because each of their mutants was mutated in a single gene, they concluded that each mutated gene must normally dictate the production of one enzyme. Their results supported the one gene–one enzyme hypothesis and also confirmed the arginine pathway.
(Notice that a mutant can grow only if supplied with a compound made *after* the defective step.)



- Beadle and Tatum developed the “one gene–one enzyme hypothesis”
  - Which states that the function of a gene is to dictate the production of a specific enzyme

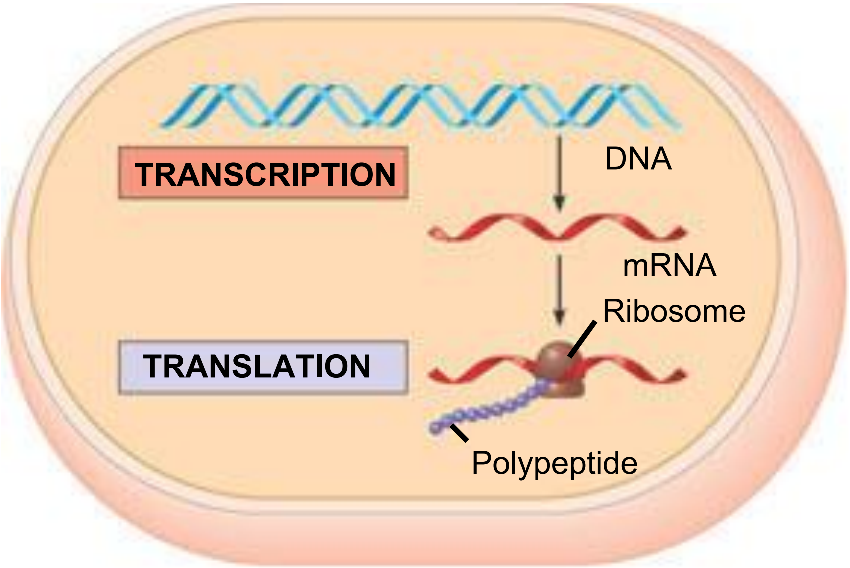
The Products of Gene Expression: A Developing Story

- As researchers learned more about proteins
  - The made minor revision to the one gene–one enzyme hypothesis
- Genes code for polypeptide chains or for RNA molecules

Basic Principles of Transcription and Translation

- 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

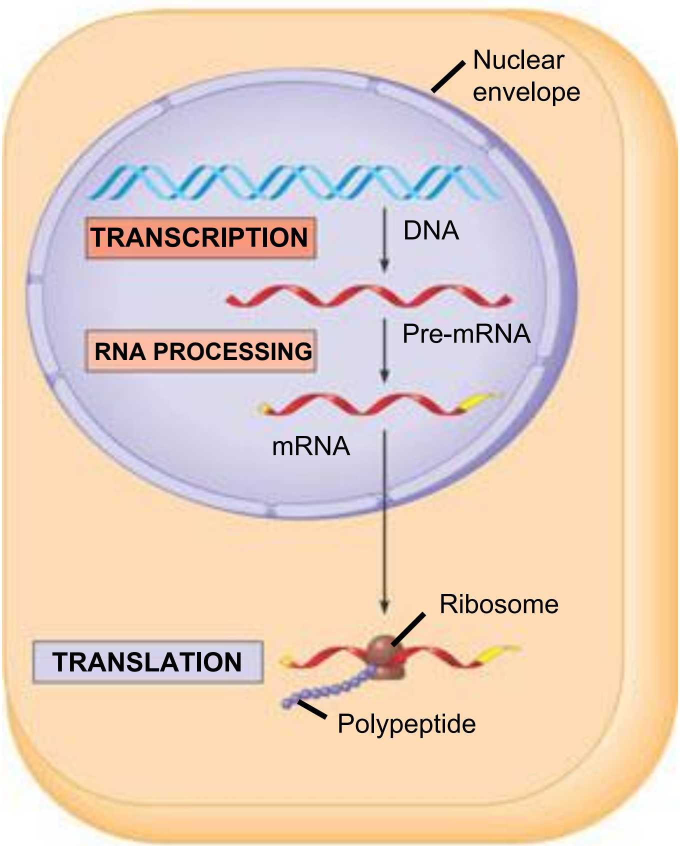
- In prokaryotes
  - Transcription and translation occur together



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

Figure 17.3a

- In eukaryotes
  - RNA transcripts are modified before becoming true mRNA



(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.

Figure 17.3b

- Cells are governed by a cellular chain of command
  - DNA → RNA → protein

The Genetic Code

- How many bases correspond to an amino acid?

Codons: Triplets of Bases

- Genetic information
  - Is encoded as a sequence of nonoverlapping base triplets, or codons

- During transcription
  - The gene determines the sequence of bases along the length of an mRNA molecule

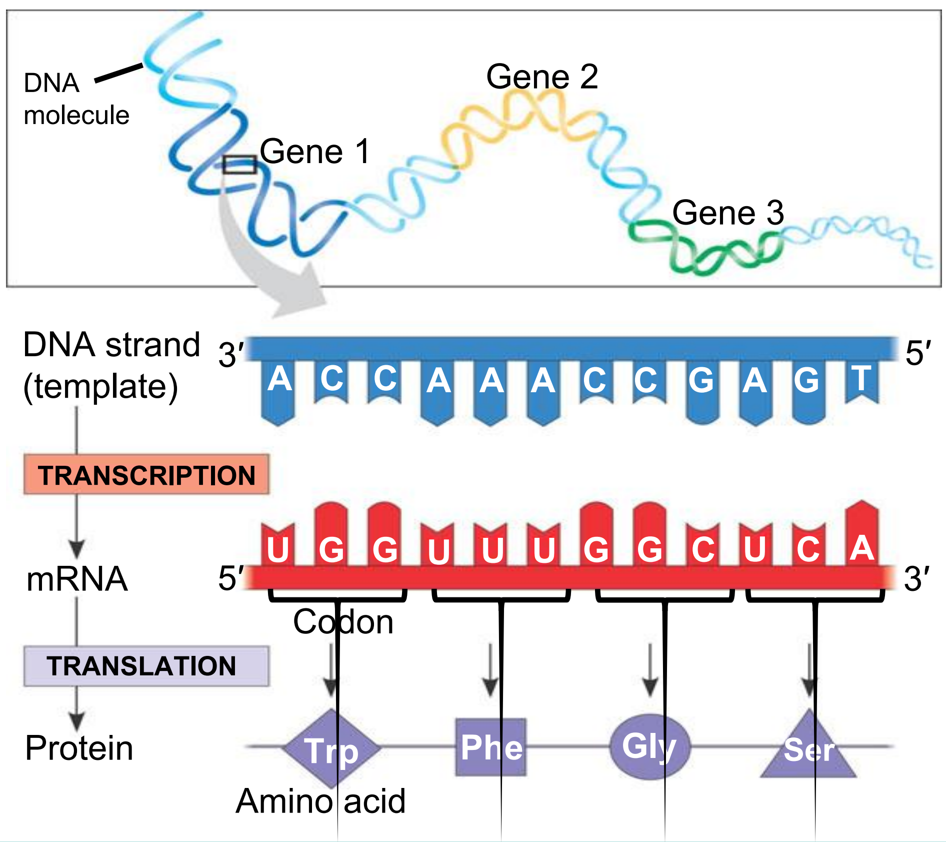


Figure 17.4

Cracking the Code

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

Second mRNA base

First mRNA base (5′ end)	U	C	A	G	Third mRNA base (3′ end)
U	UUU Phe	UCU Ser	UAU Tyr	UGU Cys	U
	UUC Phe	UCC Ser	UAC Tyr	UGC Cys	C
	UUA Leu	UCA Ser	UAA Stop	UGA Stop	A
	UUG Leu	UCG Ser	UAG Stop	UGG Trp	G
C	CUU Leu	CCU Pro	CAU His	CGU Arg	U
	CUC Leu	CCC Pro	CAC His	CGC Arg	C
	CUA Leu	CCA Pro	CAA Gln	CGA Arg	A
	CUG Leu	CCG Pro	CAG Gln	CGG Arg	G
A	AUU Ile	ACU Thr	AAU Asn	AGU Ser	U
	AUC Ile	ACC Thr	AAC Asn	AGC Ser	C
	AUA Ile	ACA Thr	AAA Lys	AGA Arg	A
	AUG Met or start	ACG Thr	AAG Lys	AGG Arg	G
G	GUU Val	GCU Ala	GAU Asp	GGU Gly	U
	GUC Val	GCC Ala	GAC Asp	GGC Gly	C
	GUA Val	GCA Ala	GAA Glu	GGA Gly	A
	GUG Val	GCG Ala	GAG Glu	GGG Gly	G

Figure 17.5

- Codons must be read in the correct reading frame
  - For the specified polypeptide to be produced

Evolution of the Genetic Code

- The genetic code is nearly universal
  - Shared by organisms from the simplest bacteria to the most complex animals

- In laboratory experiments
  - Genes can be transcribed and translated after being transplanted from one species to another

Figure 17.6

- Concept 17.2: Transcription is the DNA-directed synthesis of RNA: *a closer look*

Molecular Components of Transcription

- 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

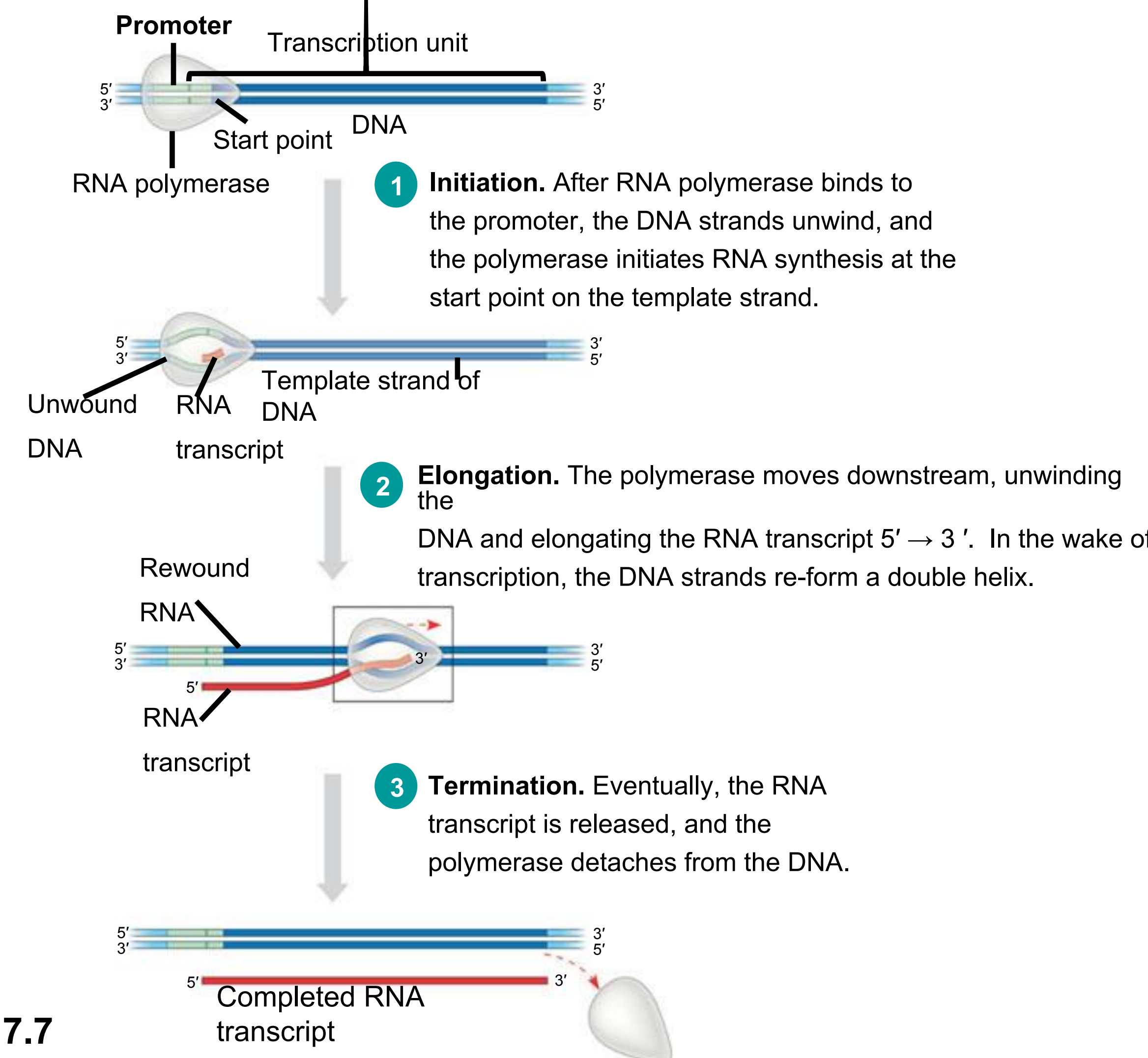
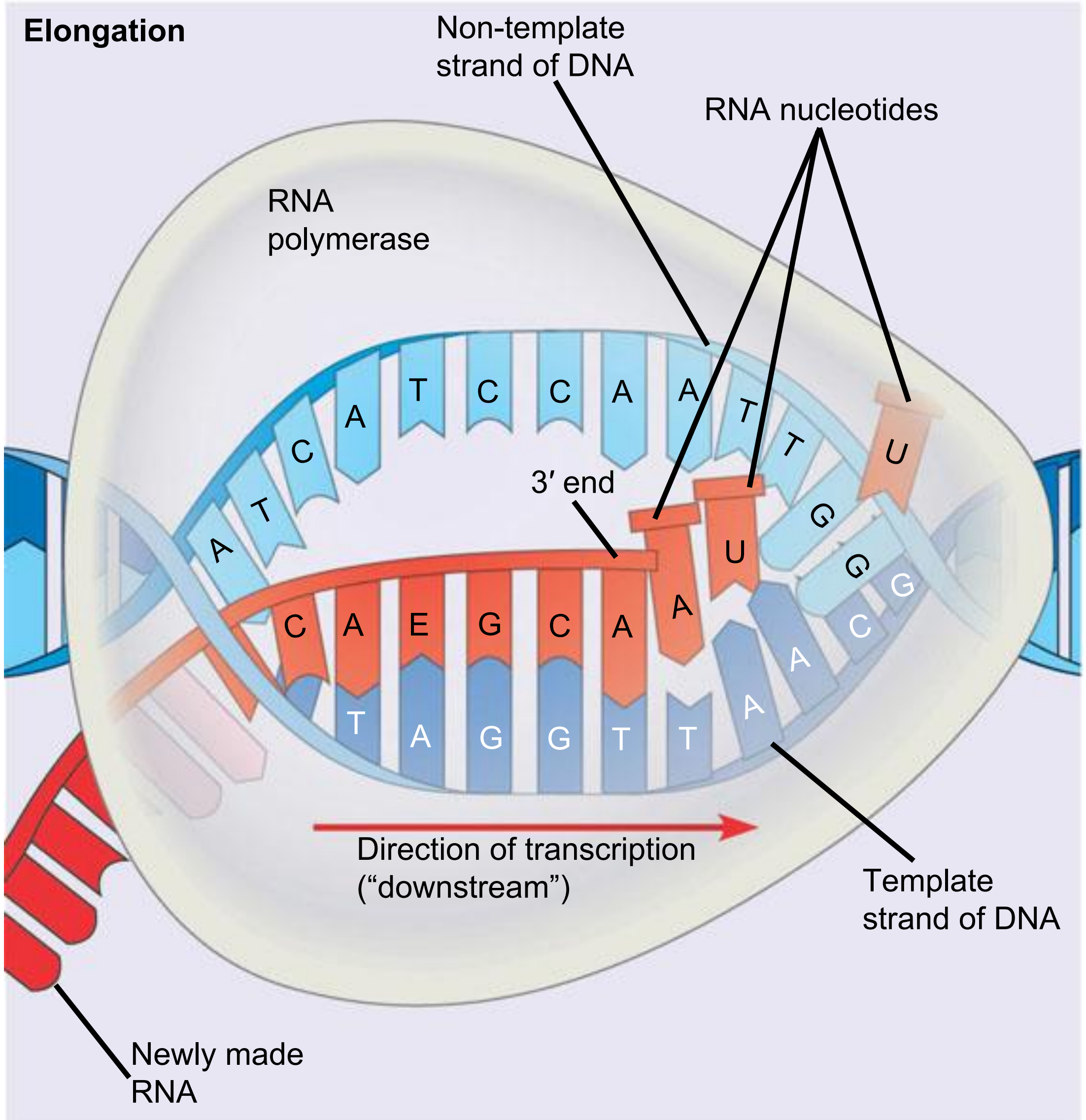


Figure 17.7

Elongation



Elongation
Non-template strand of DNA
RNA nucleotides
RNA polymerase
3′
A T C A T C C A A T T G G
3′ end
U
U
A
C A E G C A
5′
T A G G T T A A C C G
Direction of transcription ("downstream")
5′
Template strand of DNA
Newly made RNA

RNA Polymerase Binding and Initiation of Transcription

- Promoters signal the initiation of RNA synthesis
- Transcription factors
  - Help eukaryotic RNA polymerase recognize promoter sequences

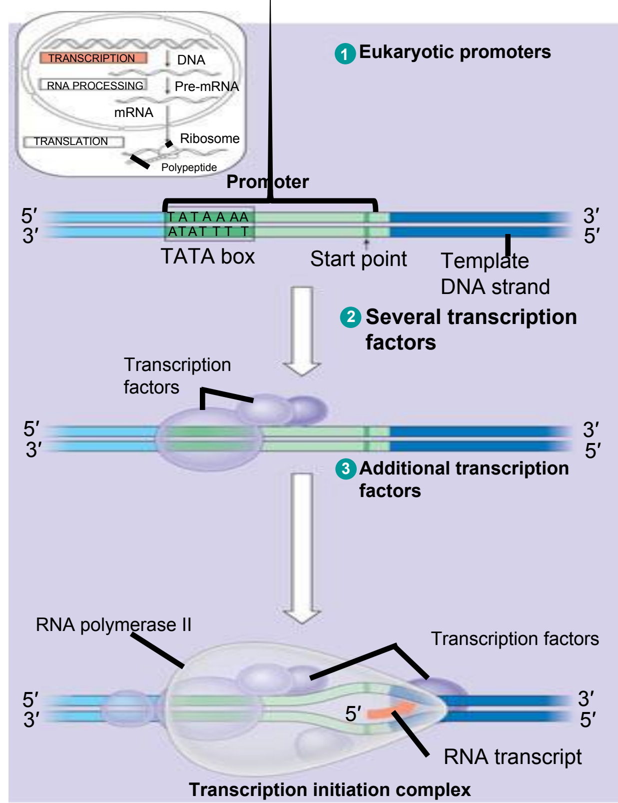


Figure 17.8

Elongation of the RNA Strand

- As RNA polymerase moves along the DNA
  - It continues to untwist the double helix, exposing about 10 to 20 DNA bases at a time for pairing with RNA nucleotides

Termination of Transcription

- The mechanisms of termination
  - Are different in prokaryotes and eukaryotes

- Concept 17.3: Eukaryotic cells modify RNA after transcription
- Enzymes in the eukaryotic nucleus
  - Modify pre-mRNA in specific ways before the genetic messages are dispatched to the cytoplasm

Difference b/w prokaryotic & eukaryotic Transcription.

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

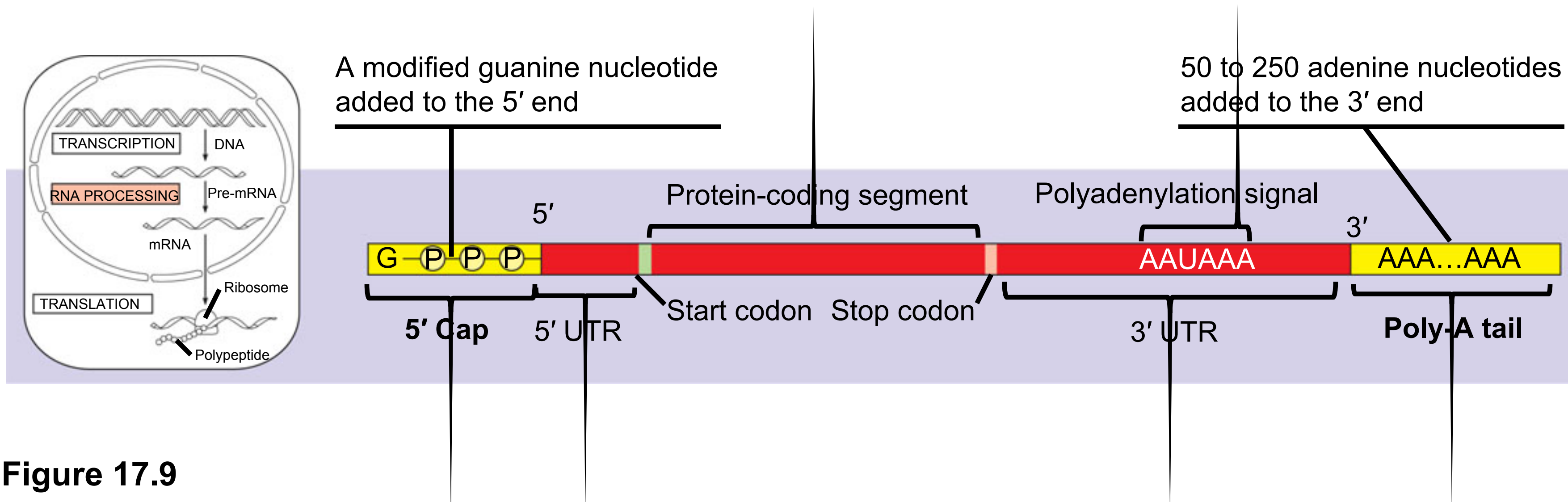


Figure 17.9

Split Genes and RNA Splicing

- RNA splicing
  - Removes introns and joins exons

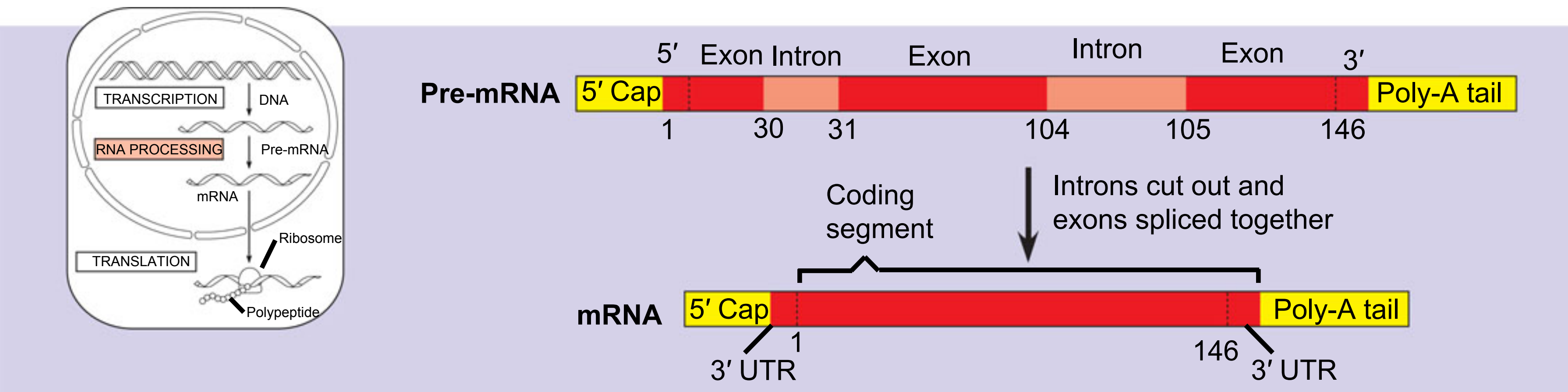


Figure 17.10

- Is carried out by spliceosomes in some cases

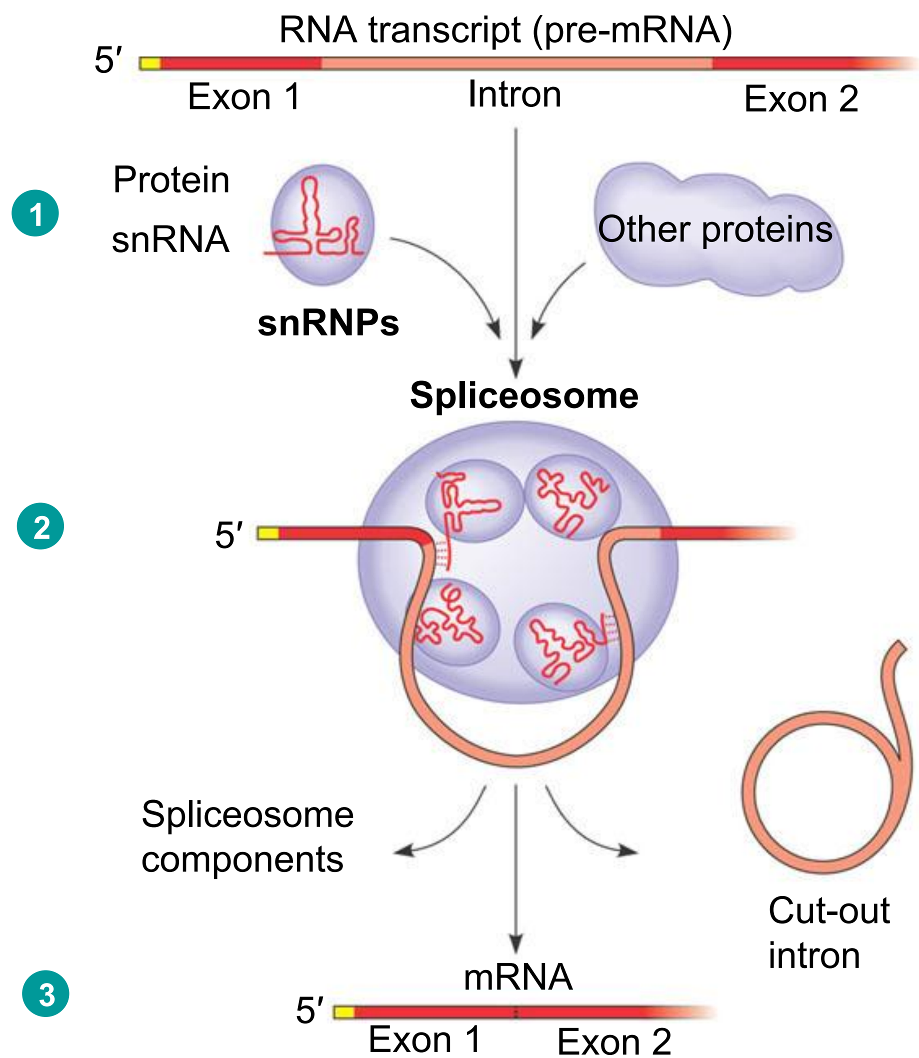


Figure 17.11

Ribozymes

- Ribozymes
  - Are catalytic RNA molecules that function as enzymes and can splice RNA

The Functional and Evolutionary Importance of Introns

- The presence of introns
  - Allows for alternative RNA splicing

- Proteins often have a modular architecture
  - Consisting of discrete structural and functional regions called domains
- In many cases
  - Different exons code for the different domains in a protein

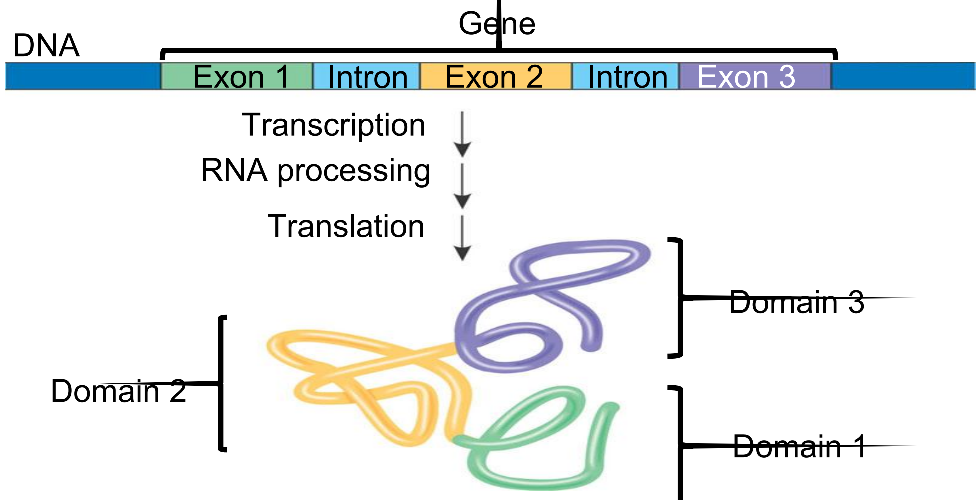


Figure 17.12

- Concept 17.4: Translation is the RNA-directed synthesis of a polypeptide: *a closer look*

Molecular Components of Translation

- A cell translates an mRNA message into protein
  - With the help of transfer RNA (tRNA)

Figure 17.13

- Translation: the basic concept

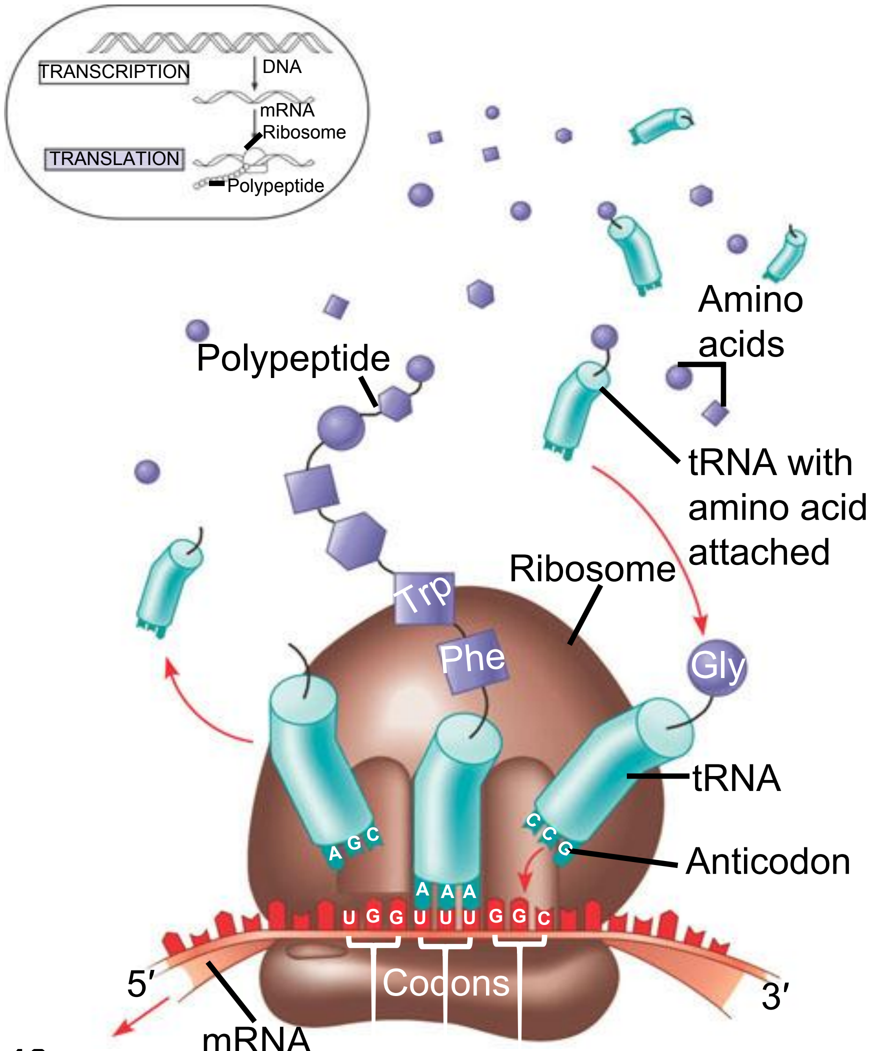
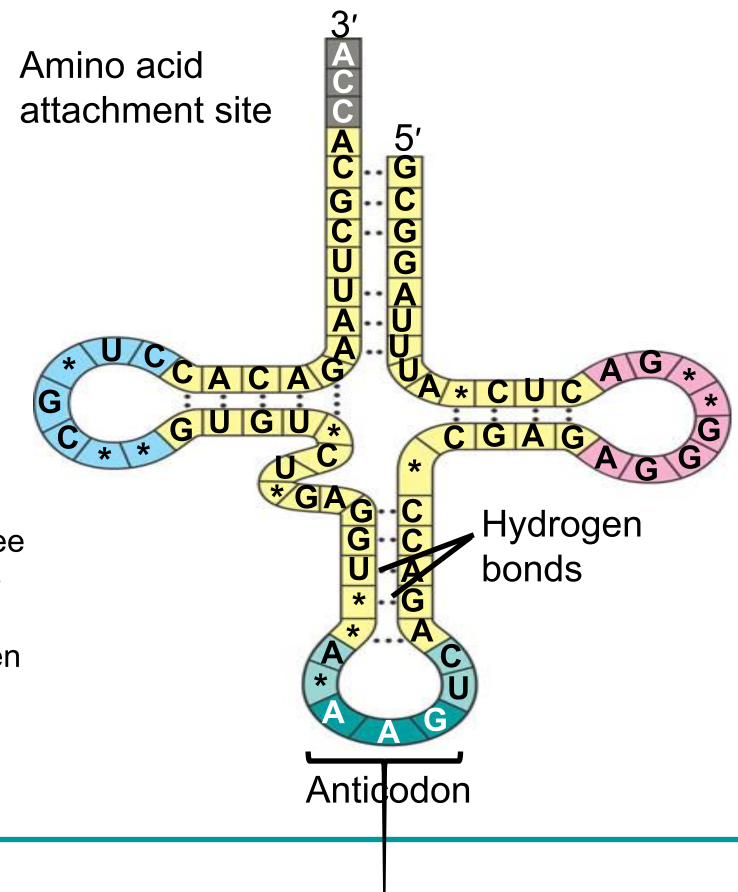


Figure 17.13

- Molecules of tRNA are not all identical
  - Each carries a specific amino acid on one end
  - Each has an anticodon on the other end

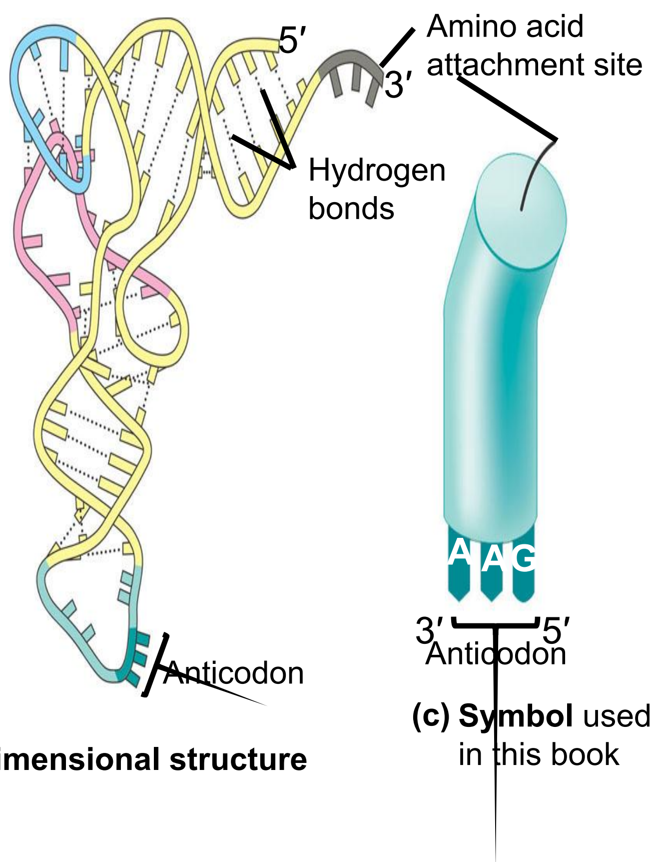
The Structure and Function of Transfer RNA

- A tRNA molecule
  - Consists of a single RNA strand that is only about 80 nucleotides long
  - Is roughly L-shaped



(a) **Two-dimensional structure.** The four base-paired regions and three loops are characteristic of all tRNAs, as is the base sequence of the amino acid attachment site at the 3′ end. The anticodon triplet is unique to each tRNA type. (The asterisks mark bases that have been chemically modified, a characteristic of tRNA.)

Figure 17.14a



(b) Three-dimensional structure

(c) Symbol used in this book

Figure 17.14b

Figure 17.15

- A specific enzyme called an aminoacyl-tRNA synthetase
  - Joins each amino acid to the correct tRNA

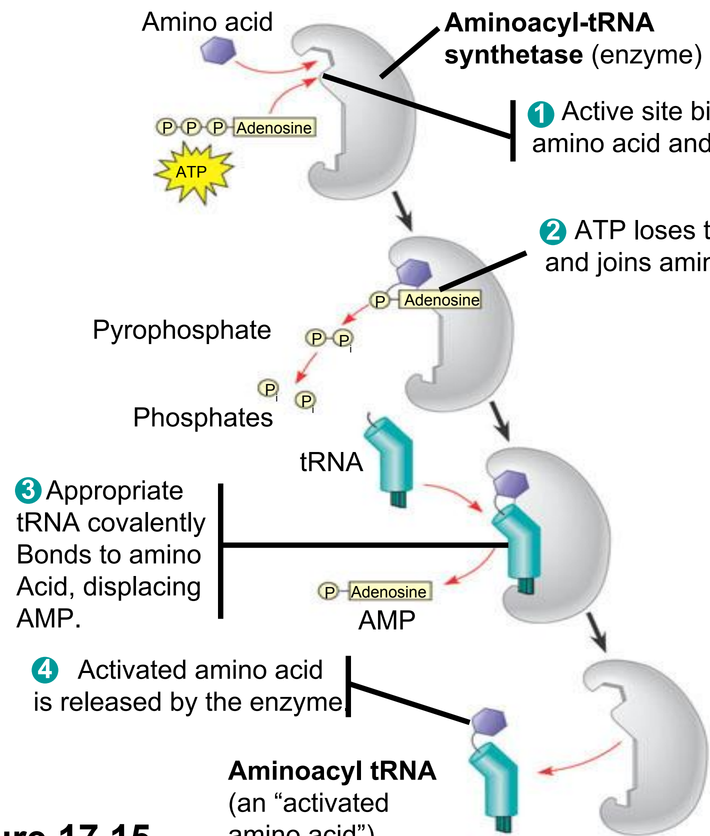
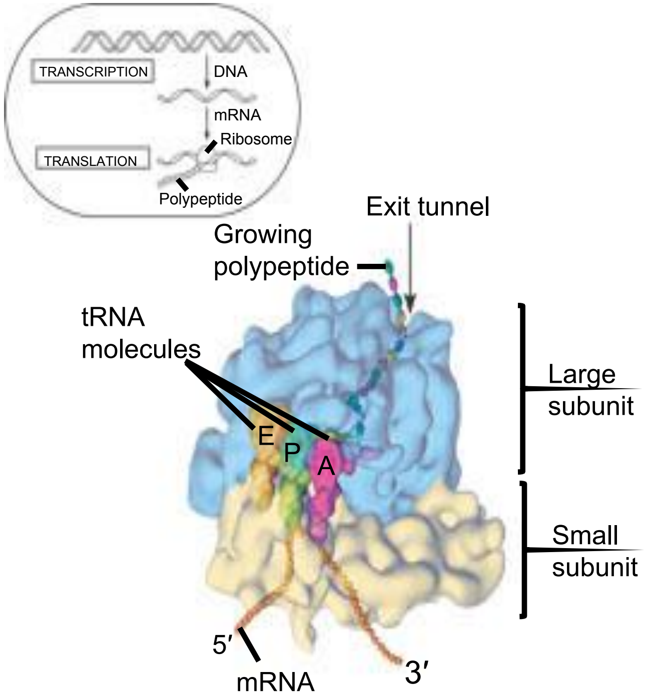


Figure 17.15

Ribosomes

- Ribosomes
  - Facilitate the specific coupling of tRNA anticodons with mRNA codons during protein synthesis

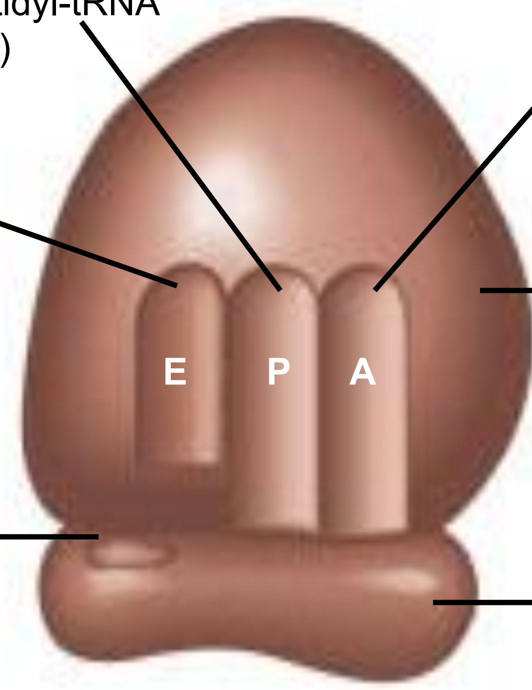
- The ribosomal subunits
  - Are constructed of proteins and RNA molecules named ribosomal RNA or rRNA



(a) Computer model of functioning ribosome. This is a model of a bacterial ribosome, showing its overall shape. The eukaryotic ribosome is roughly similar. A ribosomal subunit is an aggregate of ribosomal RNA molecules and proteins.

Figure 17.16a

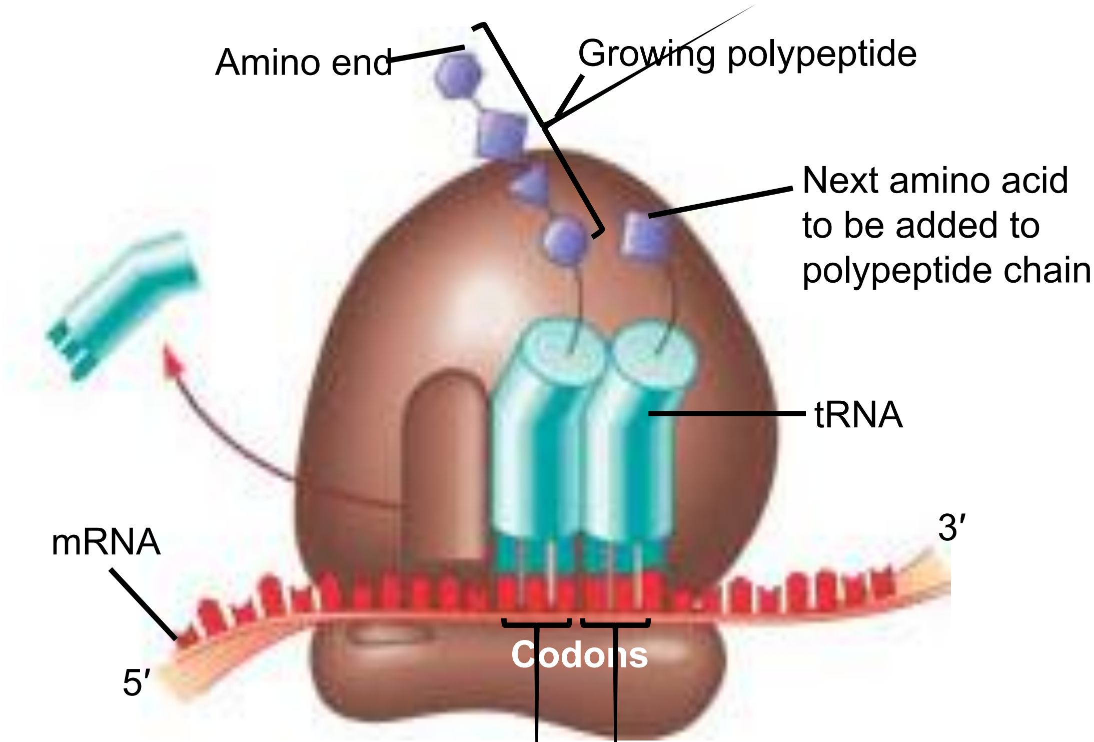
- The ribosome has three binding sites for tRNA
  - The P site
  - The A site
  - The E site



(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.

Figure 17.16b

Figure 17.16c



(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.

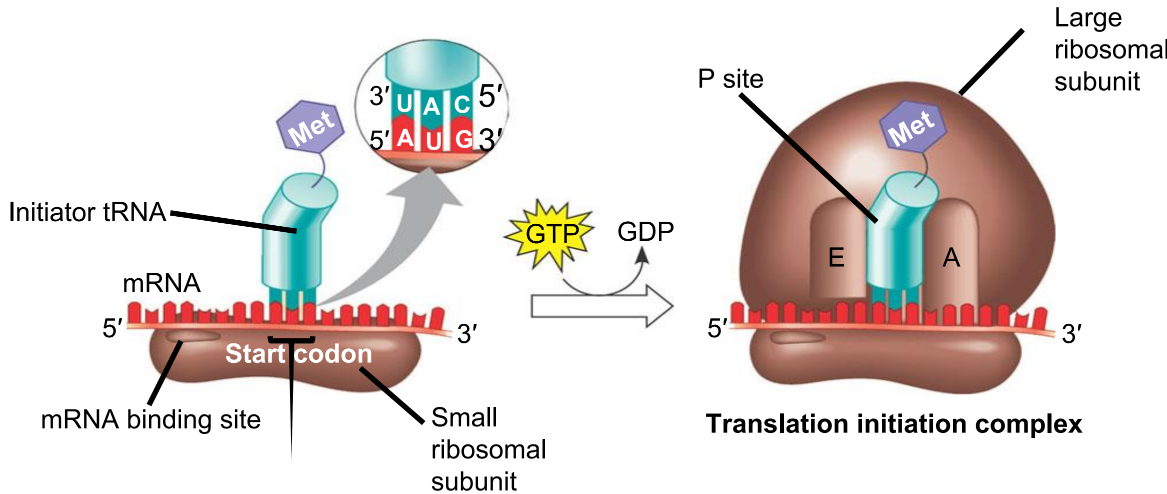
Figure 17.16c

Building a Polypeptide

- We can divide translation into three stages
  - Initiation
  - Elongation
  - Termination

Ribosome Association and Initiation of Translation

- The initiation stage of translation
  - Brings together mRNA, tRNA bearing the first amino acid of the polypeptide, and two subunits of a ribosome



1. A small ribosomal subunit binds to a molecule of mRNA. In a prokaryotic cell, the mRNA binding site on this subunit recognizes a specific nucleotide sequence on the mRNA just upstream of the start codon. An initiator tRNA, with the anticodon UAC, base-pairs with the start codon, AUG. This tRNA carries the amino acid methionine (Met).

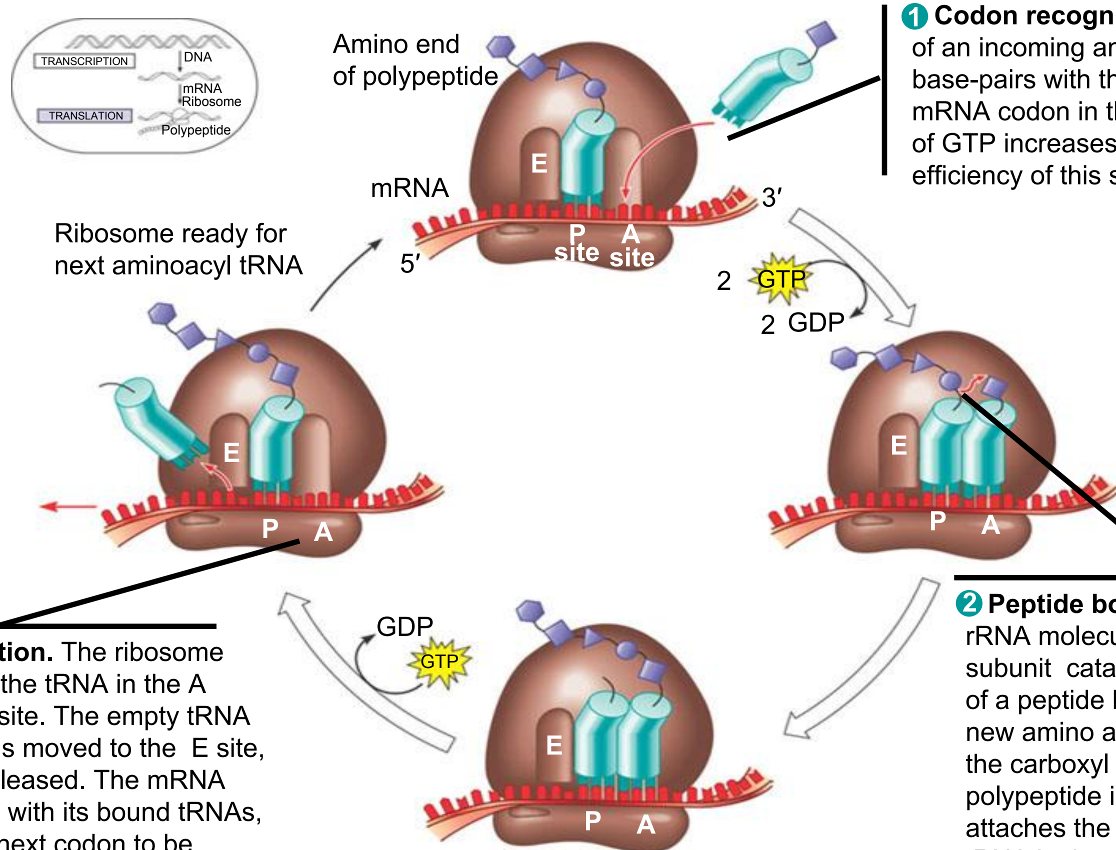
2. The arrival of a large ribosomal subunit completes the initiation complex. Proteins called initiation factors (not shown) are required to bring all the translation components together. GTP provides the energy for the assembly. The initiator tRNA is in the P site; the A site is available to the tRNA bearing the next amino acid.

Figure 17.17

Elongation of the Polypeptide Chain

- In the elongation stage of translation
  - Amino acids are added one by one to the preceding amino acid

Draw this
Imp



1 Codon recognition. The anticodon of an incoming aminoacyl tRNA base-pairs with the complementary mRNA codon in the A site. Hydrolysis of GTP increases the accuracy and efficiency of this step.

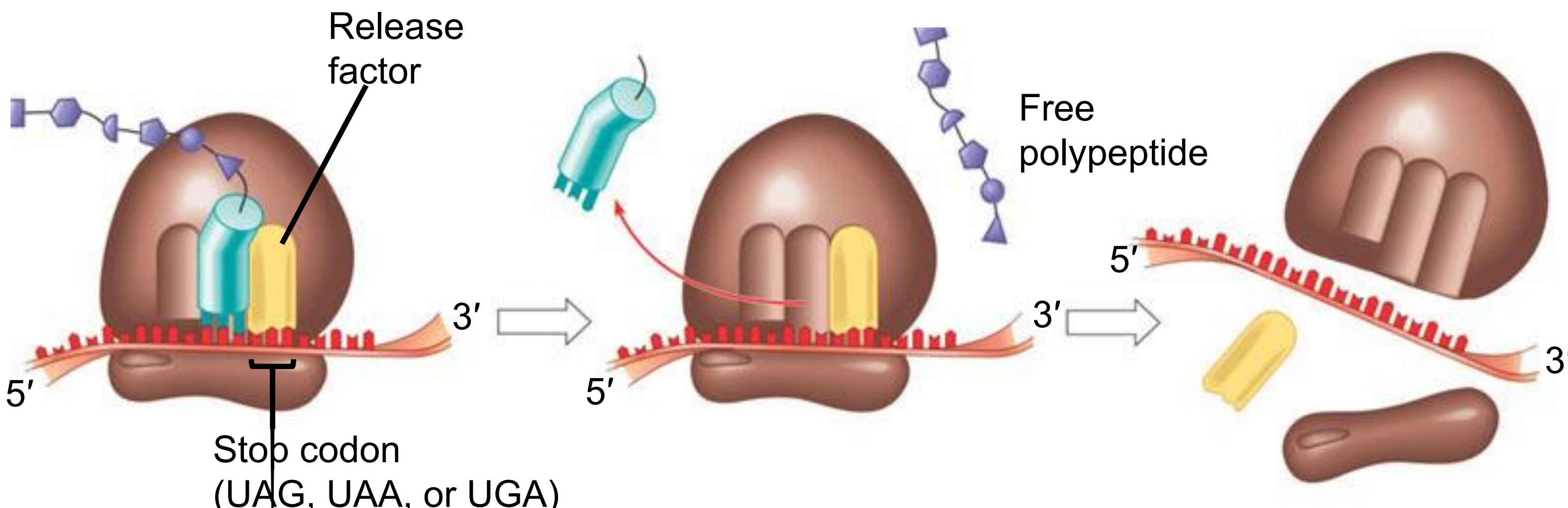
2 Peptide bond formation. An rRNA molecule of the large subunit catalyzes the formation of a peptide bond between the new amino acid in the A site and the carboxyl end of the growing polypeptide in the P site. This step attaches the polypeptide to the tRNA in the A site.

3 Translocation. The ribosome translocates the tRNA in the A site to the P site. The empty tRNA in the P site is moved to the E site, where it is released. The mRNA moves along with its bound tRNAs, bringing the next codon to be translated into the A site.

Figure 17.18

Termination of Translation

- The final stage of translation is termination
  - When the ribosome reaches a stop codon in the mRNA

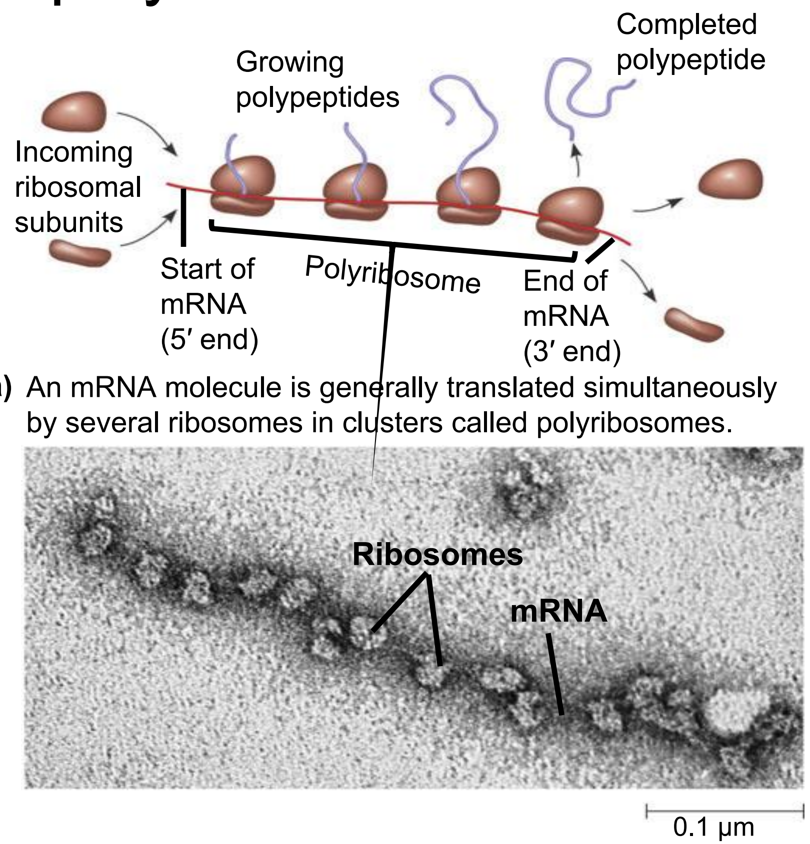


1. When a ribosome reaches a stop codon on mRNA, the A site of the ribosome accepts a protein called a release factor instead of tRNA.
2. The release factor hydrolyzes the bond between the tRNA in the P site and the last amino acid of the polypeptide chain. The polypeptide is thus freed from the ribosome.
3. The two ribosomal subunits and the other components of the assembly dissociate.

Figure 17.19

Polyribosomes

- A number of ribosomes can translate a single mRNA molecule simultaneously
  - Forming a polyribosome



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

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

Figure 17.20a, b

Completing and Targeting the Functional Protein

- Polypeptide chains
  - Undergo modifications after the translation process

Protein Folding and Post-Translational Modifications

- After translation
  - Proteins may be modified in ways that affect their three-dimensional shape

Targeting Polypeptides to Specific Locations

- Two populations of ribosomes are evident in cells
  - Free and bound
- Free ribosomes in the cytosol
  - Initiate the synthesis of all proteins

- Proteins destined for the endomembrane system or for secretion
  - Must be transported into the ER
  - Have signal peptides to which a signal-recognition particle (SRP) binds, enabling the translation ribosome to bind to the ER

- The signal mechanism for targeting proteins to the ER

imp

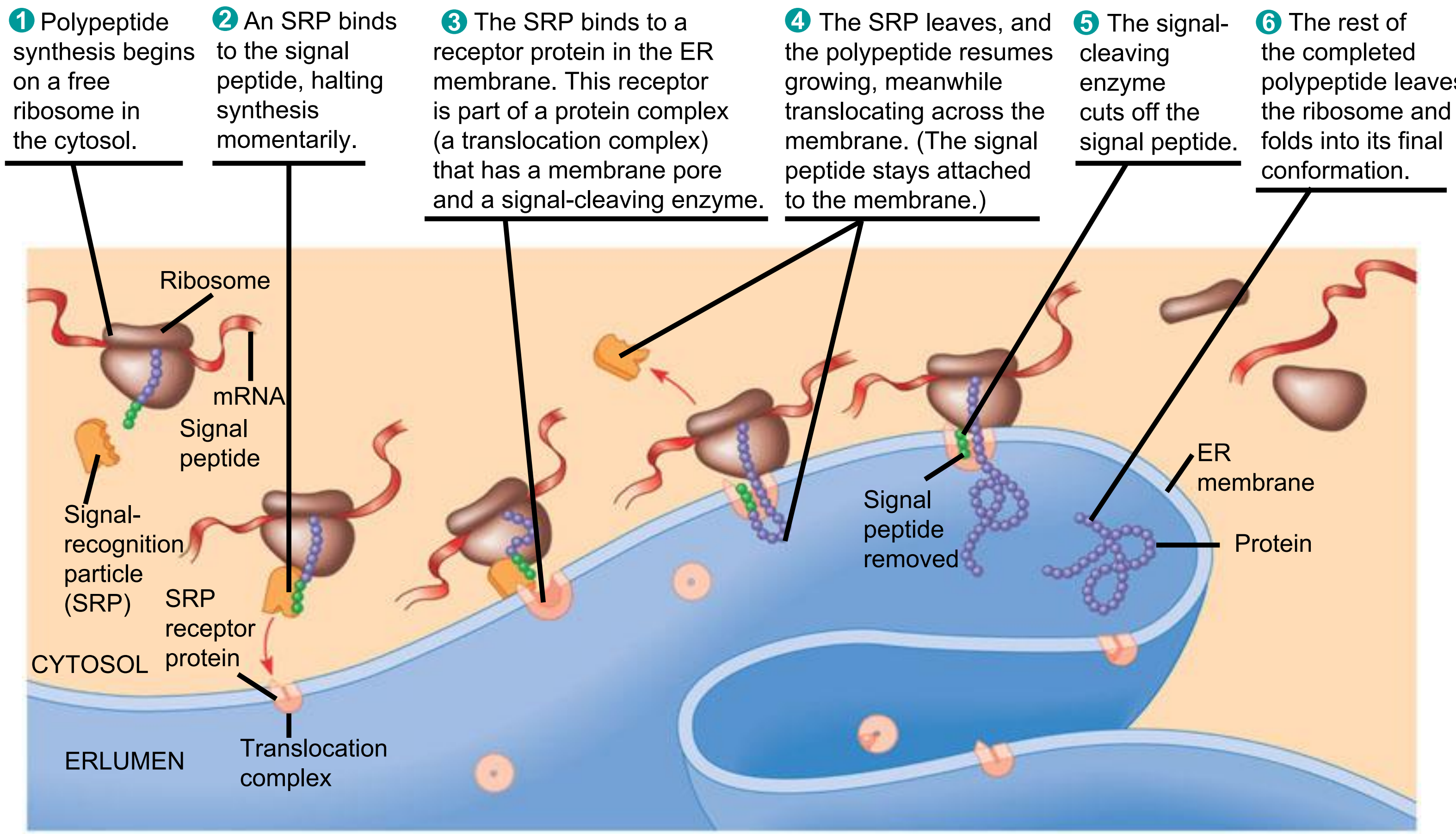


Figure 17.21

- Concept 17.5: RNA plays multiple roles in the cell: *a review*
- RNA
  - Can hydrogen-bond to other nucleic acid molecules
  - Can assume a specific three-dimensional shape
  - Has functional groups that allow it to act as a catalyst

- Types of RNA in a Eukaryotic Cell

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.
SRP RNA	Is a component of the signal-recognition particle (SRP), the protein-RNA complex that recognizes the signal peptides of polypeptides targeted to the ER.
Small nucleolar RNA (snoRNA)	Aids in processing of pre-rRNA transcripts for ribosome subunit formation in the nucleolus.
Small interfering RNA (siRNA) and microRNA (miRNA)	Are involved in regulation of gene expression.

Table 17.1

- Concept 17.6: Comparing gene expression in prokaryotes and eukaryotes reveals key differences
- Prokaryotic cells lack a nuclear envelope
  - Allowing translation to begin while transcription is still in progress

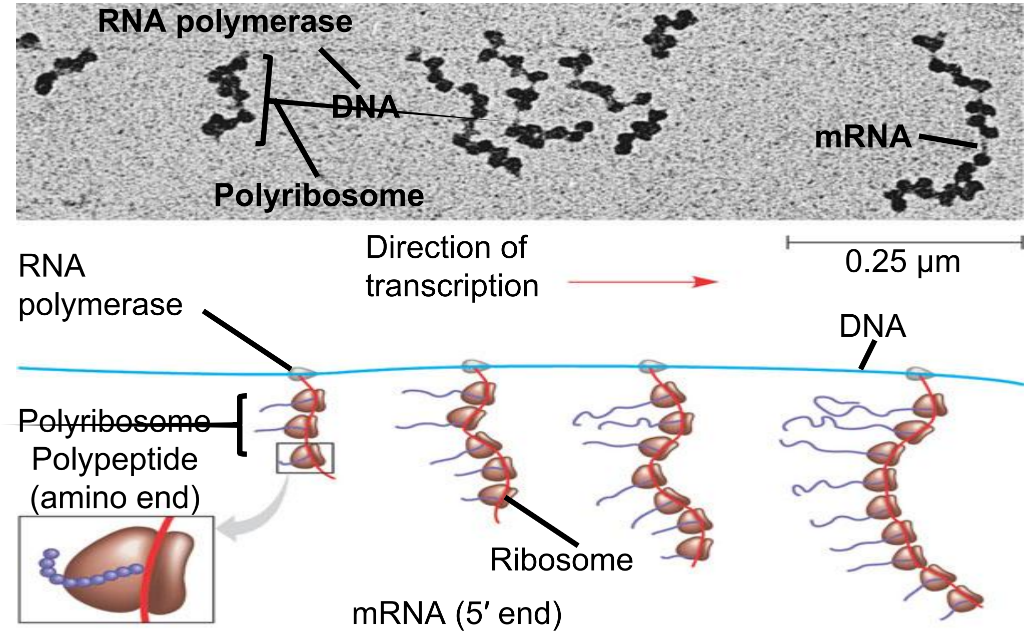
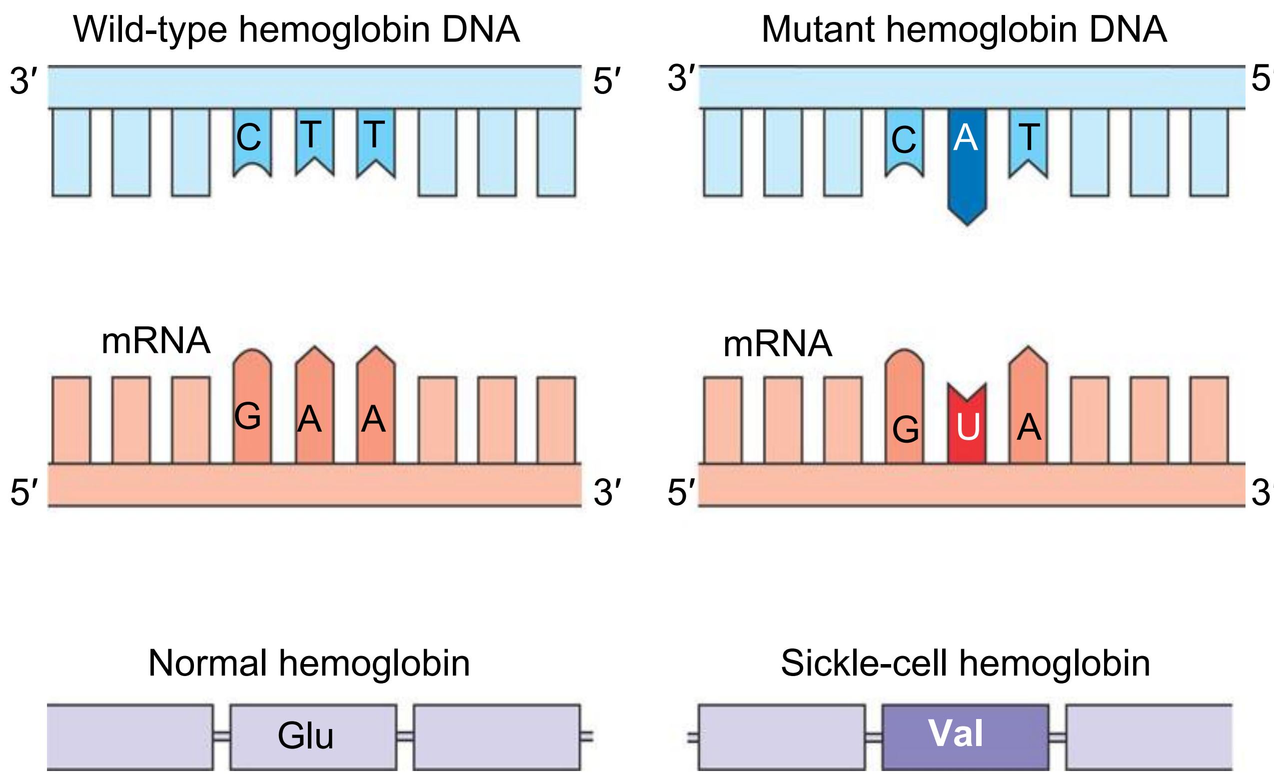


Figure 17.22

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

- Concept 17.7: Point mutations can affect protein structure and function
- Mutations
  - Are changes in the genetic material of a cell
- Point mutations
  - Are changes in just one base pair of a gene

- The change of a single nucleotide in the DNA's template strand
  - Leads to the production of an abnormal protein



In the DNA, the mutant template strand has an A where the wild-type template has a T.

The mutant mRNA has a U instead of an A in one codon.

The mutant (sickle-cell) hemoglobin has a valine (Val) instead of a glutamic acid (Glu).

Figure 17.23

Types of Point Mutations

- Point mutations within a gene can be divided into two general categories
  - Base-pair substitutions
  - Base-pair insertions or deletions

Substitutions

- A base-pair substitution
  - Is the replacement of one nucleotide and its partner with another pair of nucleotides
  - Can cause missense or nonsense

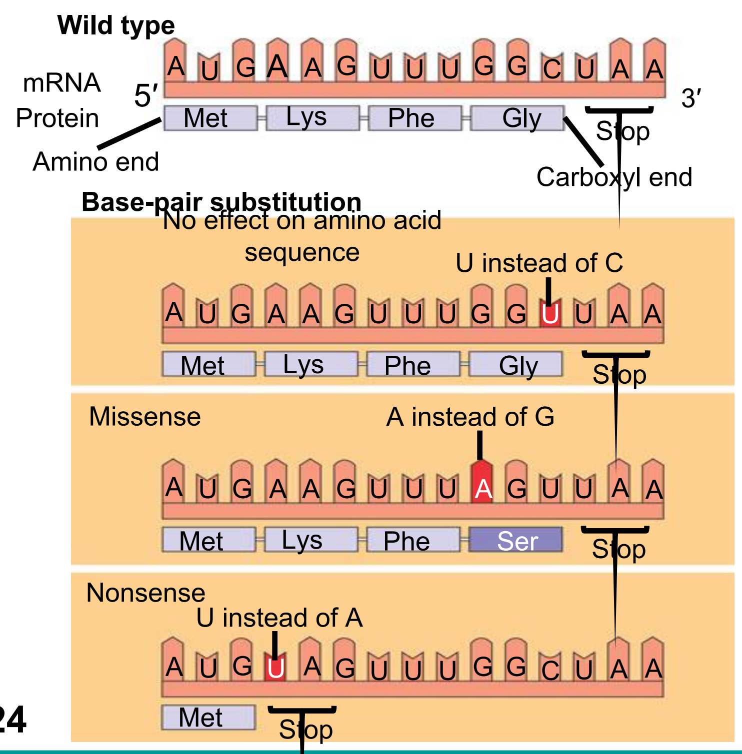


Figure 17.24

Insertions and Deletions

- Insertions and deletions
  - Are additions or losses of nucleotide pairs in a gene
  - May produce frameshift mutations

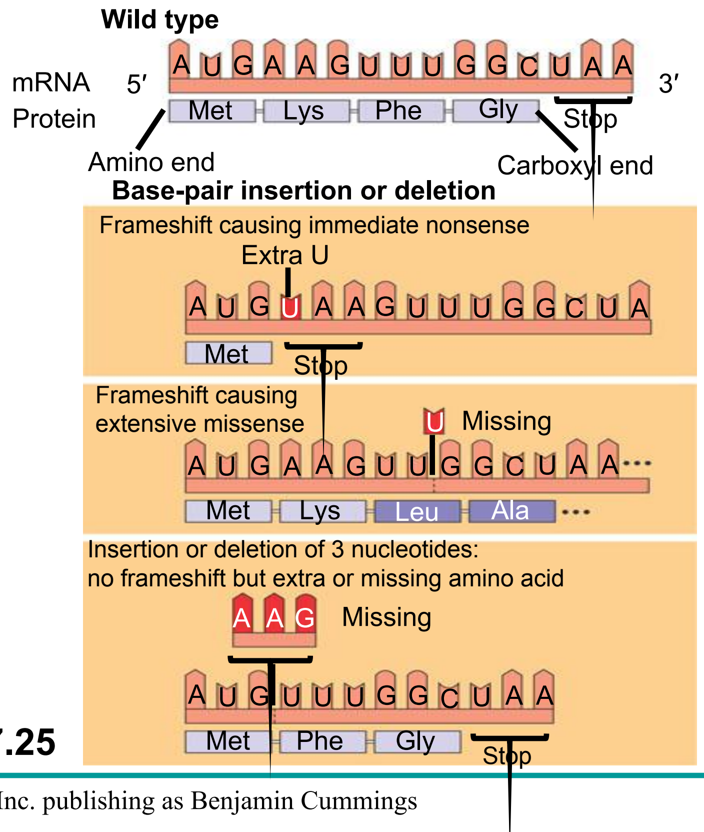


Figure 17.25

Mutagens

- Spontaneous mutations
  - Can occur during DNA replication, recombination, or repair

- Mutagens
  - Are physical or chemical agents that can cause mutations

What is a gene? *revisiting the question*

- A gene
  - Is a region of DNA whose final product is either a polypeptide or an RNA molecule

- A summary of transcription and translation in a eukaryotic cell

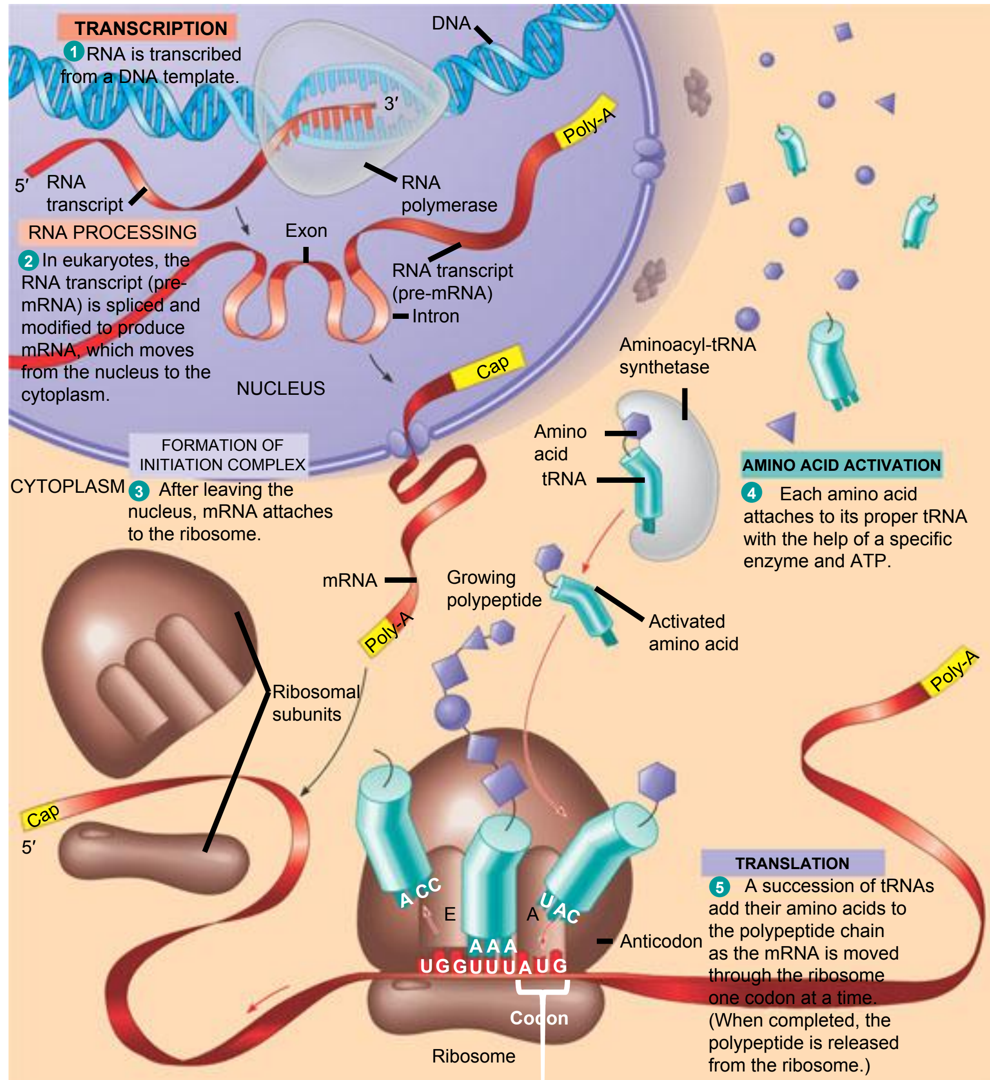


Figure 17.26