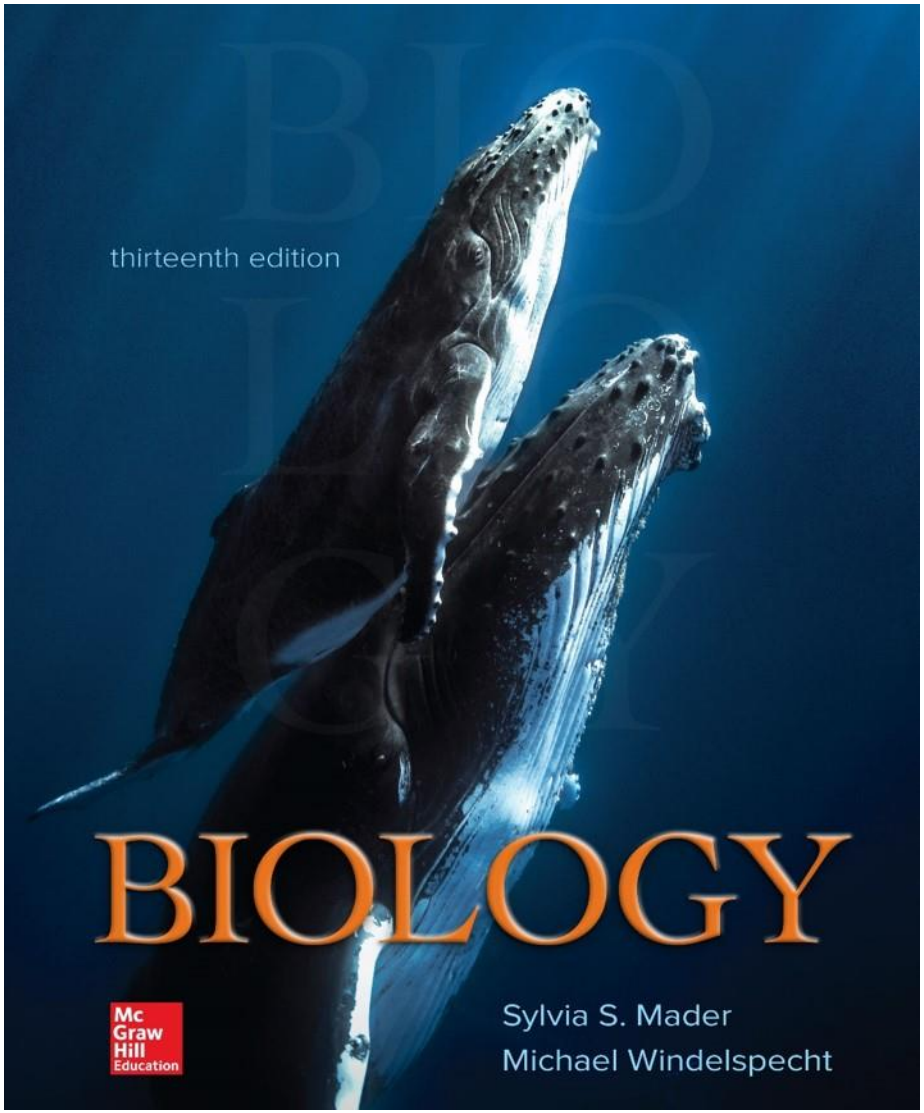


Biology

Sylvia S. Mader
Michael Windelspecht

Chapter 12
Molecular Biology of the Gene
Lecture Outline

See separate FlexArt PowerPoint slides for all figures and tables pre-inserted into PowerPoint without notes.

Outline

12.1 The Genetic Material

12.2 Replication of DNA

12.3 Gene Expression: RNA and the Genetic Code

12.4 Gene Expression: Transcription

12.5 Gene Expression: Translation

The Genetic Material (7)

DNA contains:

- Two nucleotides with purine bases
  - **Adenine (A)**
  - **Guanine (G)**
- Two nucleotides with pyrimidine bases
  - **Thymine (T)**
  - **Cytosine (C)**

Nucleotide Composition of DNA

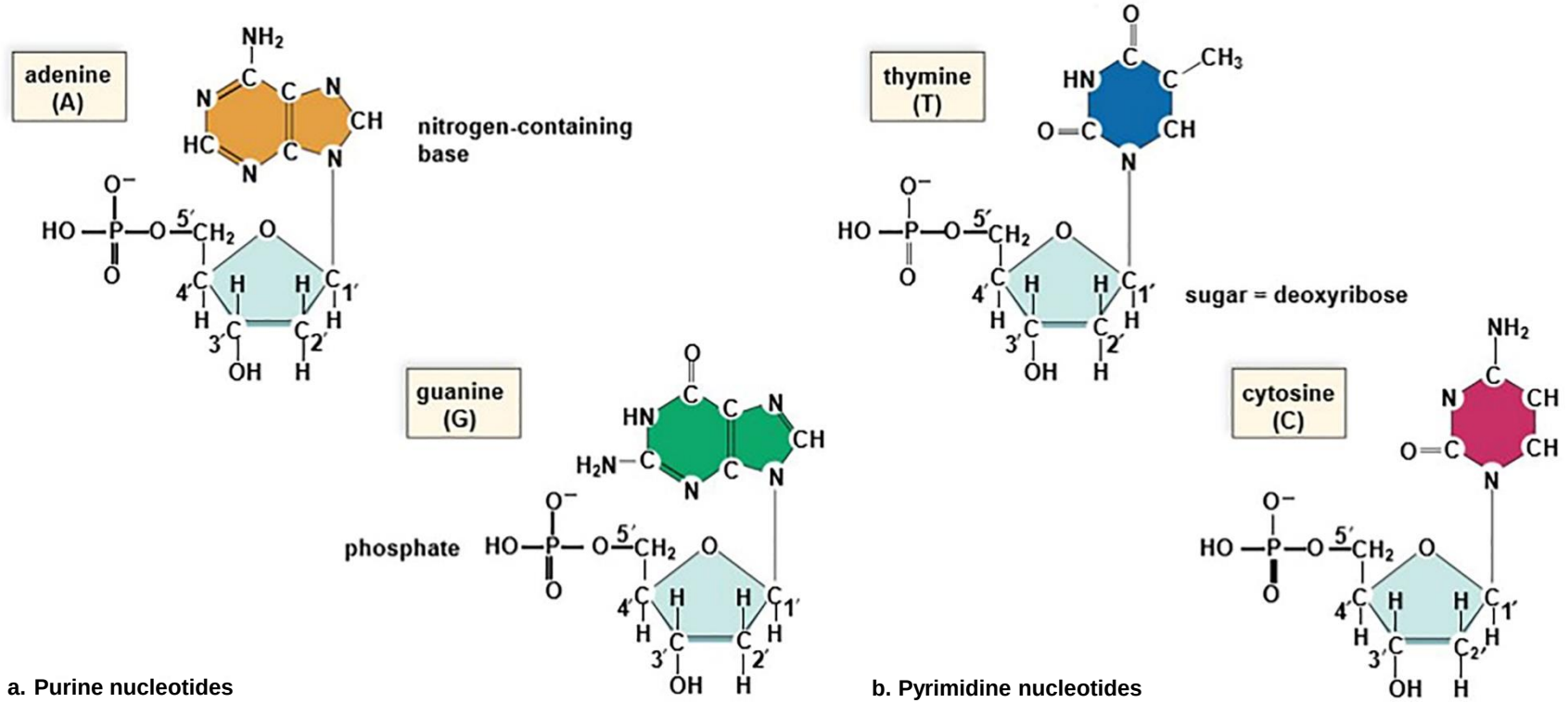


Table 12.1 DNA Composition in Various Species (%)

Species	A	T	G	C
Homo sapiens **(human)**	31.0	31.5	19.1	18.4
Drosophila melanogaster **(fruit fly)**	27.3	27.6	22.5	22.5
Zea mays **(corn)**	25.6	25.3	24.5	24.6
Neurospora crassa **(fungus)**	23.0	23.3	27.1	26.6
Escherichia coli **(bacterium)**	24.6	24.3	25.5	25.6
Bacillus subtilis **(bacterium)**	28.4	29.0	21.0	21.6

c. Chargaff's data

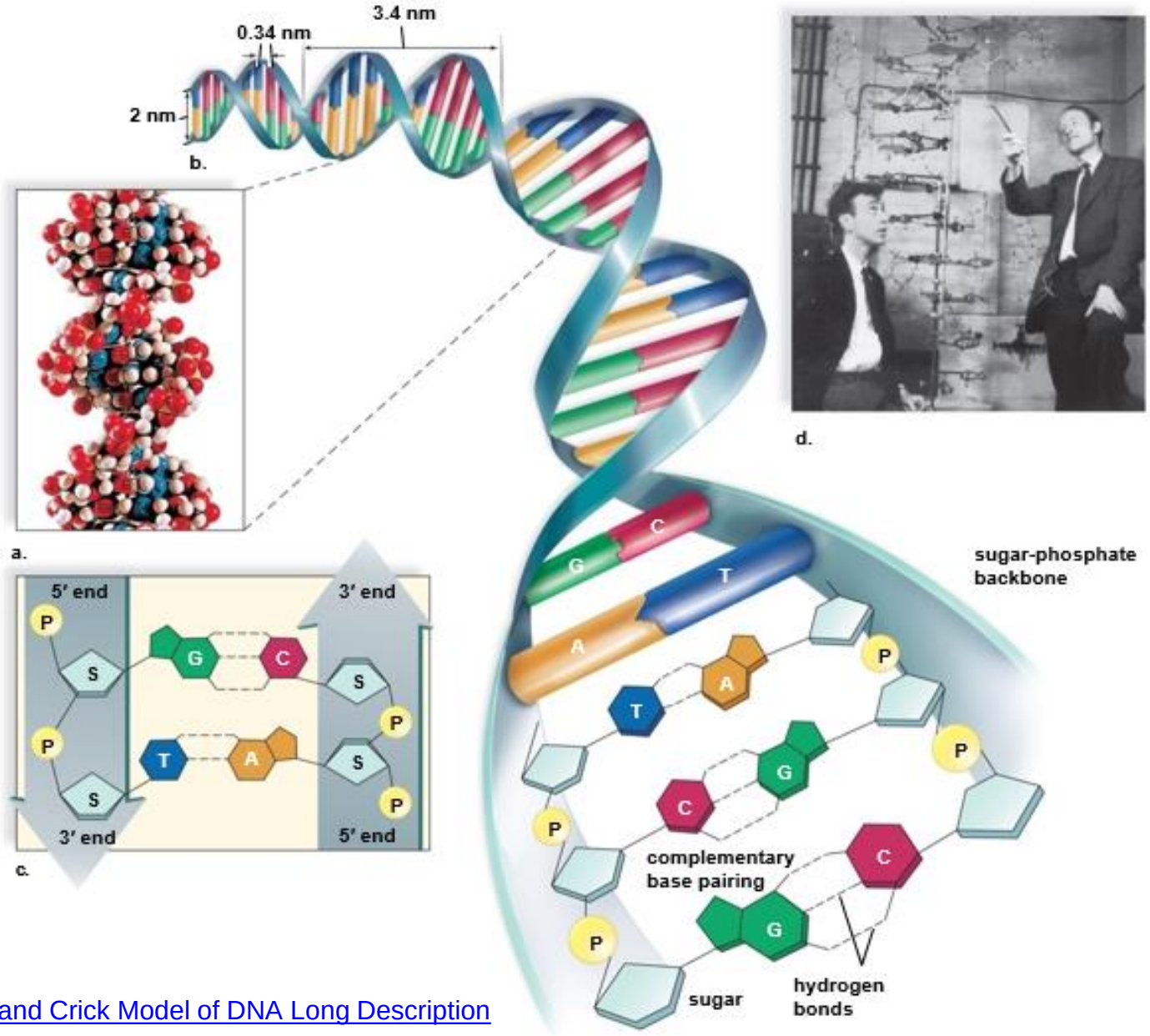
Jump to Nucleotide Composition of DNA Long Description

The Genetic Material (10)

The Watson and Crick Model (1953)

- **Double helix** model is similar to a twisted ladder.
  - Sugar-phosphate backbones make up the sides.
  - Hydrogen-bonded bases make up the rungs.
  - The two DNA strands are antiparallel.
  - Information stored in DNA must be read in the 5 prime to 3 prime direction so DNA is replicated in a 5 prime to 3 prime direction.
- Complementary base pairing ensures that a purine is always bonded to a pyrimidine (A with T, G with C).
- They received a Nobel Prize in 1962.

Watson and Crick Model of DNA



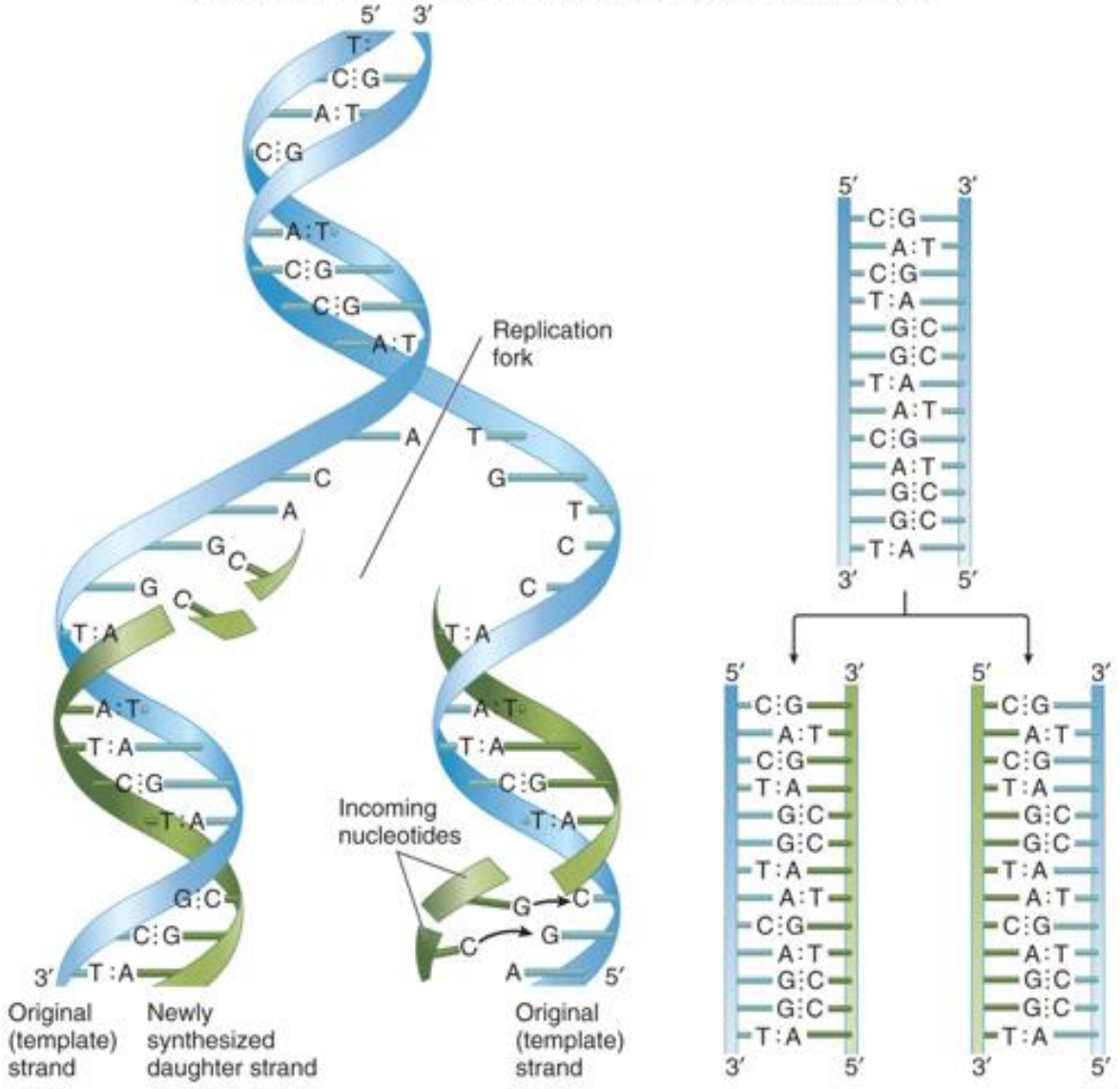
Jump to Watson and Crick Model of DNA Long Description

12.2 Replication of DNA

DNA replication is the process of copying a DNA molecule.

Semiconservative replication: Each strand of the original double helix (*parental* molecule) serves as a **template** (mold or model) for a new strand in a daughter molecule.

Semiconservative Replication



a. The mechanism of DNA replication

b. The products of replication

[Jump to Semiconservative Replication Long Description]

Replication of DNA (1)

Replication requires the following steps:

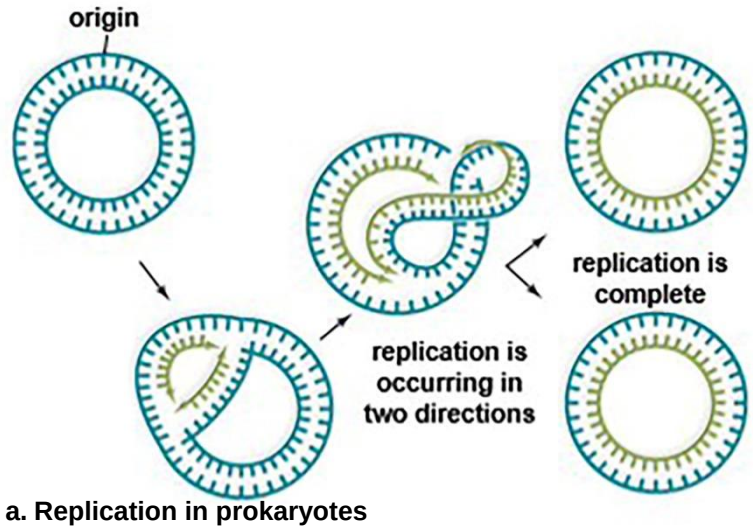
- Unwinding, or separation, of the two strands of the parental DNA molecule by the DNA helicase enzyme
- Single-stranded binding proteins (SSB) attach to newly separated DNA and prevent helix from re-forming.
- Complementary base pairing between a new nucleotide and a nucleotide on the template strand
  - DNA primase places short primers on the strands to be replicated.
  - Polymerase recognizes RNA and begins DNA synthesis.
    - The two strands are replicated differently: leading and lagging strands.
    - Joining of nucleotides in the lagging strand by DNA ligase form the new strand.
  - Each daughter DNA molecule contains one old and one new strand.

Replication of DNA (3)

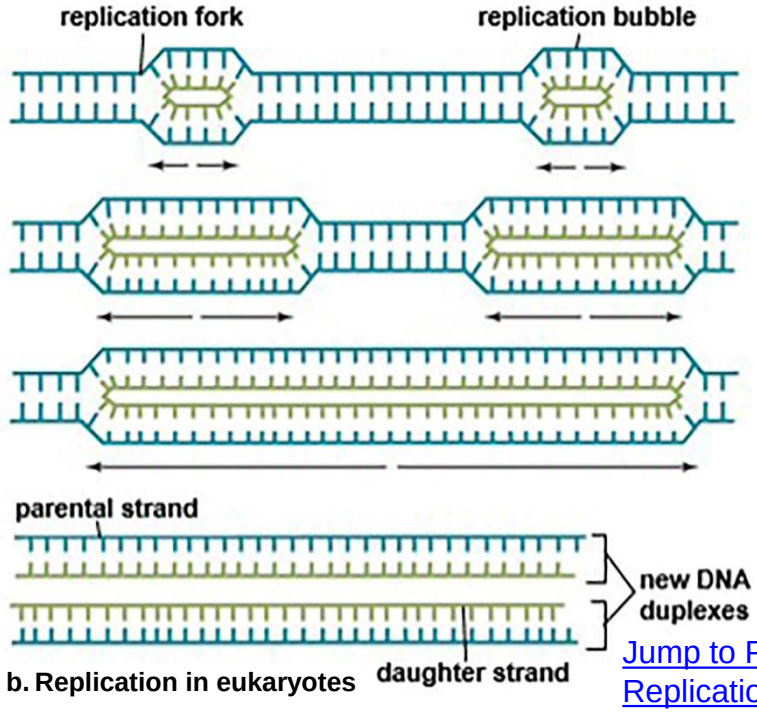
Eukaryotic Replication

- DNA replication begins at numerous points along each linear chromosome.
- DNA unwinds and unzips into two strands.
- Each old strand of DNA serves as a template for a new strand.
- Complementary base pairing forms a new strand paired with each old strand.
  - Requires enzyme **DNA polymerase**

Prokaryotic versus Eukaryotic Replication



a. Replication in prokaryotes



b. Replication in eukaryotes

Jump to Prokaryotic versus Eukaryotic Replication Long Description

Replication of DNA (5)

Accuracy of Replication

- DNA polymerase is very accurate, yet makes a mistake about once per 100,000 base pairs.
  - Capable of identifying and correcting errors

12.3 Gene Expression: RNA and the Genetic Code

Genes Specify Enzymes

- Archibald Garrod described inborn errors of metabolism.
- Beadle and Tatum:
  - Experiments on the fungus *Neurospora crassa*
  - Proposed that each gene specifies the synthesis of one enzyme
  - One gene, one enzyme hypothesis

The flow of genetic information is from DNA to RNA to protein to an observed trait.

Gene Expression: RNA and the Genetic Code (1)

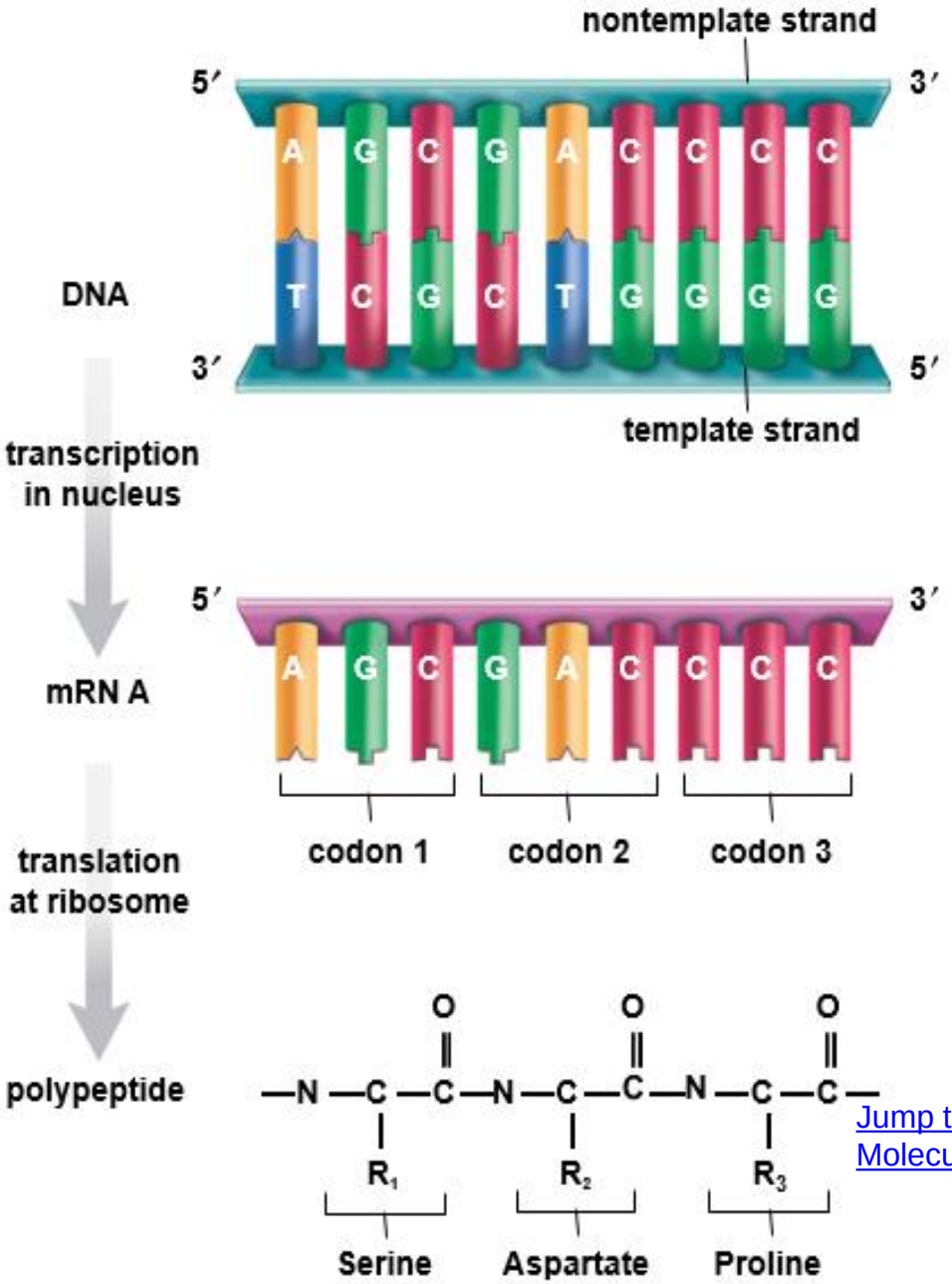
The mechanism of gene expression

- DNA in genes specify information, but information is not structure and function.
- Genetic information is expressed into structure and function through protein synthesis.

The expression of genetic information into structure and function:

- DNA in a gene determines the sequence of nucleotides in an RNA molecule.
- RNA controls the primary structure of a protein.

The Central Dogma of Molecular Biology (3)



Jump to The Central Dogma of Molecular Biology (3) Long Description

Gene Expression: RNA and the Genetic Code (2)

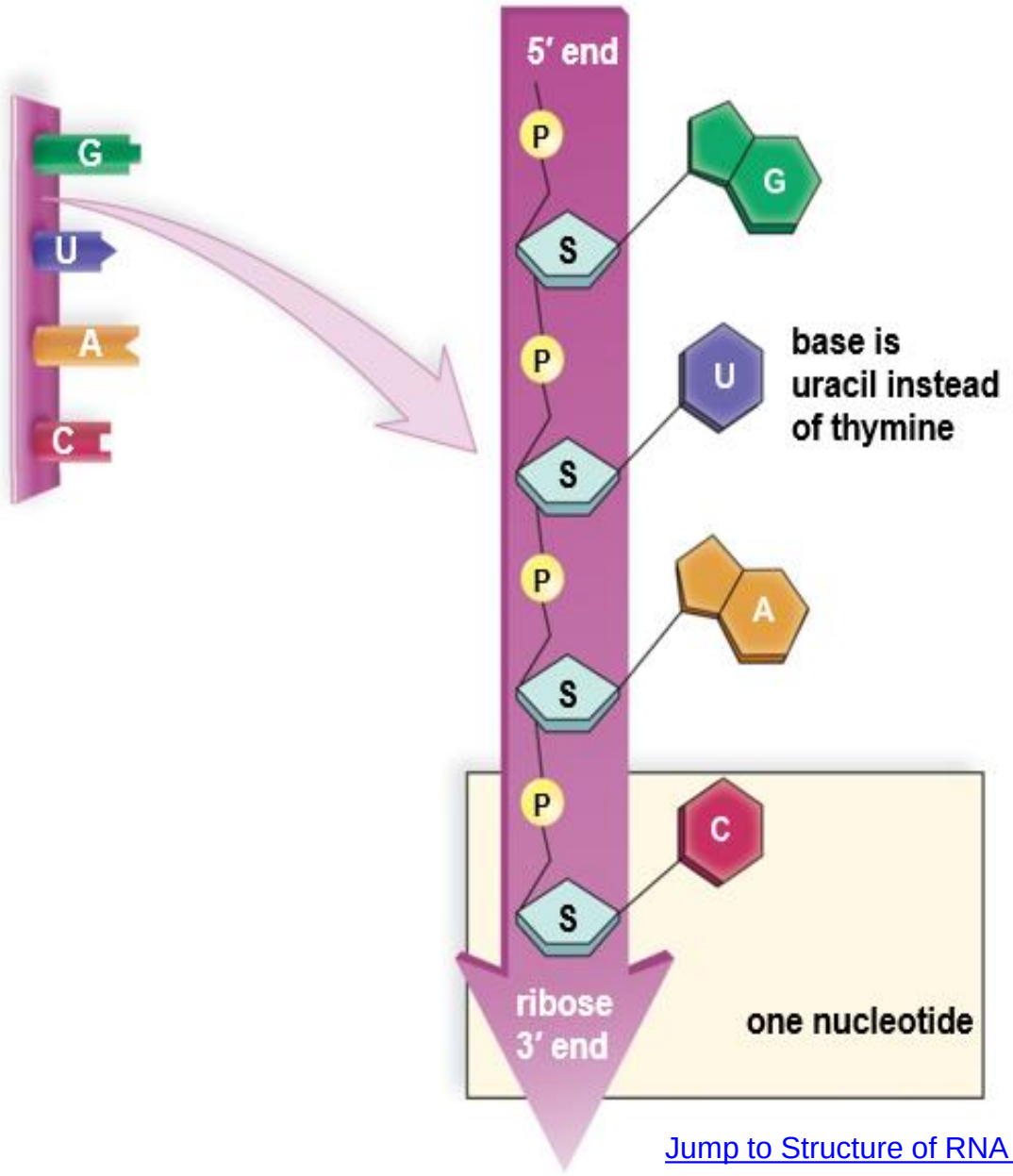
RNA is a polymer of RNA nucleotides.

- RNA nucleotides contain the sugar ribose instead of deoxyribose.
- RNA nucleotides are of four types: **uracil (U), adenine (A), cytosine (C)**, and **guanine (G).**
- Uracil (U) replaces thymine (T) of DNA.

Types of RNA

- **Messenger (mRNA)** takes a message from DNA in the nucleus to ribosomes in the cytoplasm.
- **Ribosomal (rRNA),** along with ribosomal proteins, make up ribosomes, where polypeptides are synthesized.
- **Transfer (tRNA)** transfers the appropriate amino acid to the ribosomes.

Structure of RNA



Jump to Structure of RNA Long Description

RNA Structure Compared to DNA Structure

Table 12.3 RNA Structure Compared to DNA Structure

	RNA	**DNA**
Sugar	Ribose	Deoxyribose
Bases	Adenine, guanine, uracil, cytosine	Adenine, guanine, thymine, cytosine
Strands	Single-stranded	Double-stranded with base pairing
Helix	No	Yes

The Genetic Code (1)

The unit of the **genetic code** consists of **codons**, each of which is a unique arrangement of symbols.

Each of the 20 amino acids found in proteins is uniquely specified by one or more codons.

- The symbols used by the genetic code are the mRNA bases.
  - Function as “letters” of the genetic alphabet
  - The genetic alphabet has only four “letters” (U, A, C, G).
- Codons in the genetic code are all three bases (symbols) long.
  - They function as “words” of genetic information.
  - Permutations:
    - There are 64 possible arrangements of four symbols taken three at a time.
    - They are often referred to as triplets.
  - Genetic language only has 64 “words.”

Messenger RNA Codons

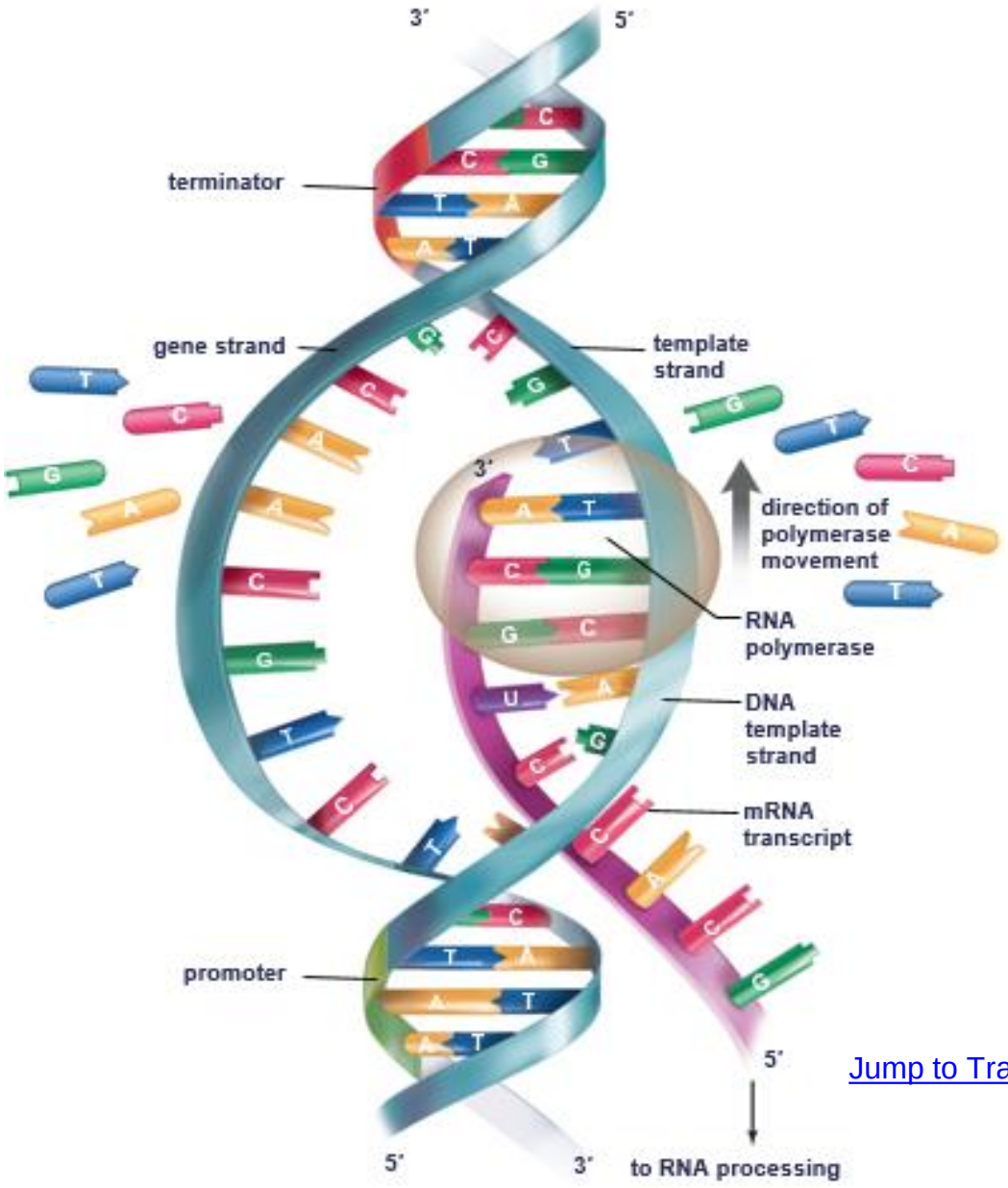
	Second Base U	Second Base C	Second Base A	Second Base G	
First base U	UUU phenylalanine	UCU serine	UAU tyrosine	UGU cysteine	Third Base U
First base U	UUC phenylalanine	UCC serine	UAC tyrosine	UGU cysteine	Third Base C
First base U	UUA leucine	UCA serine	UAA stop	UGA stop	Third Base A
First base U	UUG leucine	UCG serine	UAG stop	UGG tryptophan	Third Base G
First Base C	CUU leucine	CCU proline	CAU histidine	CGU arginine	Third Base U
First Base C	CUC leucine	CCC proline	CAC histidine	CGC arginine	Third Base C
First Base C	CUA leucine	CCA proline	CAA glutamine	CGA arginine	Third Base A
First Base C	CUG leucine	CCG proline	CAG glutamine	CGG arginine	Third Base G
First Base A	AUU isoleucine	ACU threonine	AAU asparagine	AGU serine	Third Base U
First Base A	AUC isoleucine	ACC threonine	AAC asparagine	AGC serine	Third Base C
First Base A	AUA isoleucine	ACA threonine	AAA lysine	AGA arginine	Third Base A
First Base A	AUG (start) methionine	ACG threonine	AAG lysine	AGG arginine	Third Base G
First Base G	GUU valine	GCU alanine	GAU aspartate	GGU glycine	Third Base U
First Base G	GUC valine	GCC alanine	GAC aspartate	GGC glycine	Third Base C
First Base G	GUA valine	GCA alanine	GAA glutamate	GGA glycine	Third Base A
First Base G	GUG valine	GCG alanine	GAG glutamate	GGG glycine	Third Base G

12.4 Gene Expression: Transcription

Transcription

- A segment of DNA serves as a template for the production of an RNA molecule.
- The gene unzips and exposes unpaired bases.
- It serves as a template for mRNA formation.
- Loose RNA nucleotides bind to exposed DNA bases using the C = G and A = U rule.
- When the entire gene is transcribed into mRNA, the result is a **pre-mRNA transcript** of the gene.
- The base sequence in the pre-mRNA is complementary to the base sequence in DNA.

Transcription



Jump to Transcription Long Description

First Step: Transcription (1)

Pre-mRNA is modified (or processed) before leaving the eukaryotic nucleus.

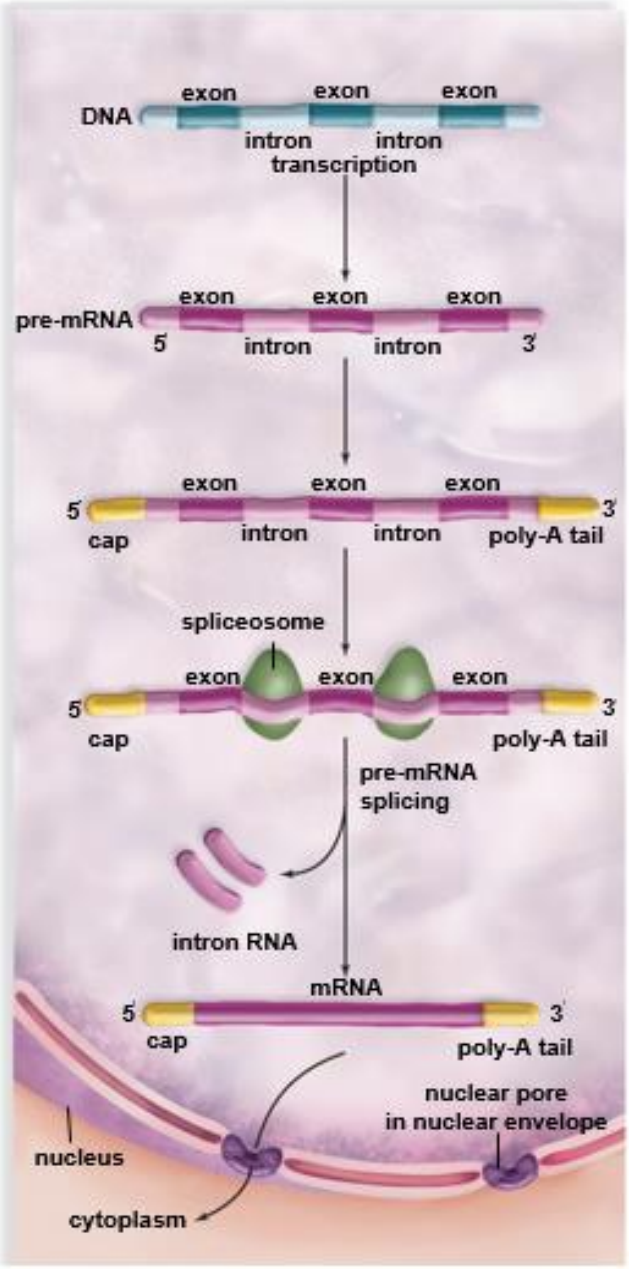
- Modifications to the ends of the primary transcript:
  - Cap on the 5 prime end
    - The *cap* is a modified guanine (G) nucleotide.
    - It helps a ribosome determine where to attach when translation begins.
  - Poly-A tail of 150 to 200 adenines on the 3 prime end
    - It facilitates the transport of mRNA out of the nucleus.
    - It inhibits degradation of mRNA by hydrolytic enzymes.

First Step: Transcription (2)

Pre-mRNA is composed of **exons** and **introns**.

- The exons will be *ex*pressed.
- The introns occur *in* between the exons.
  - The exons are “expressed” and the introns are “in the way.”
  - It allows a cell to pick and choose which exons go into a particular mRNA.
- RNA splicing:
  - Primary transcript consists of:
    - Some segments that will not be expressed (introns)
    - Segments that will be expressed (exons)

Messenger RNA Processing in Eukaryotes (4)



Jump to Messenger RNA Processing in Eukaryotes (4) Long Description

12.5 Second Step: Translation

Translation

- The sequence of codons in the mRNA at a ribosome directs the sequence of amino acids into a polypeptide.
- A nucleic acid sequence is translated into a protein sequence.

Transfer RNA (or tRNA) molecules have two binding sites:

- One associates with the mRNA transcript.
- The other associates with a specific amino acid.
- Each of the 20 amino acids in proteins associates with one or more of 64 types of tRNA.
- The “wobble” hypothesis predicts that the third position in the tRNA anticodon doesn’t obey the A-U/G-C configuration rule and can be variable.

Translation

- An mRNA transcript associates with the rRNA of a ribosome in the cytoplasm or a ribosome associated with the rough endoplasmic reticulum.
- The ribosome “reads” the information in the transcript.
- The ribosome directs various types of tRNA to bring in their specific amino acid “fares.”
- The tRNA specified is determined by the code being translated in the mRNA transcript.

Second Step: Translation (1)

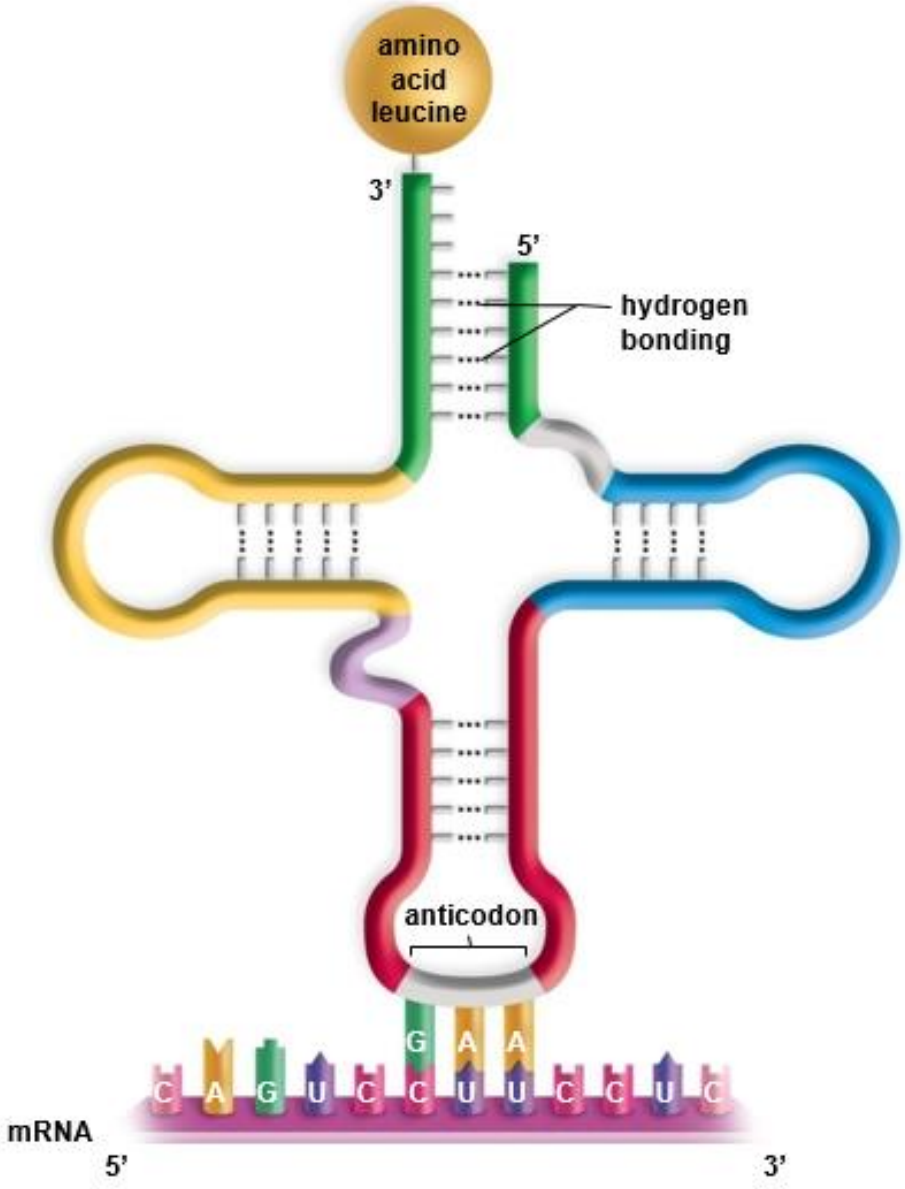
tRNA molecules come in 64 different kinds.

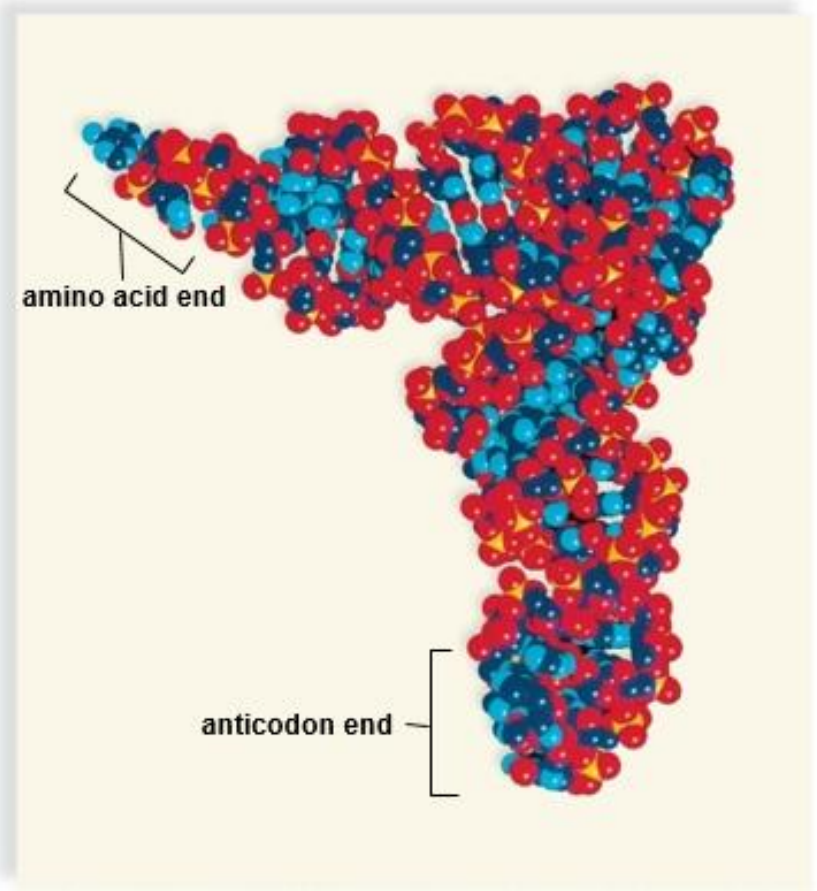
All are very similar except that

- One end bears a specific triplet (of the 64 possible) called the **anticodon**.
- The other end binds with a specific amino acid type.
- tRNA synthetases attach the correct amino acid to the correct tRNA molecule.

All tRNA molecules with a specific anticodon will always bind with the same amino acid.

Structure of a tRNA Molecule (4)





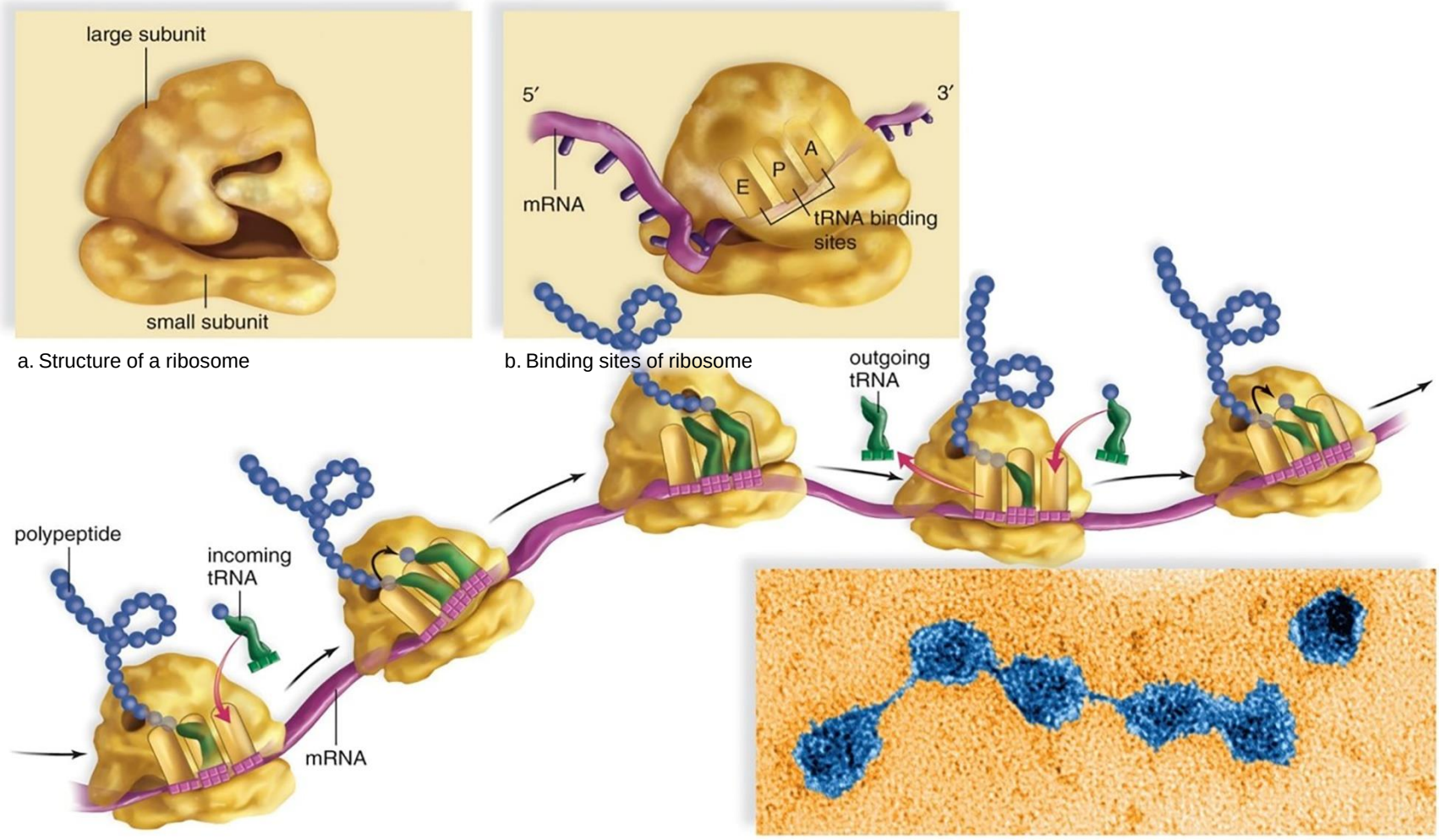
Jump to Structure of a tRNA Molecule (4) Long Description

Second Step: Translation (2)

Structure and function of ribosomes

- Ribosomal RNA (rRNA):
  - Produced from a DNA template in the nucleolus of a nucleus
  - Packaged with proteins into large and small ribosomal subunits
- A completed ribosome has three binding sites to facilitate pairing between tRNA and mRNA.
  - The E (for exit) site
  - The P (for peptide) site, and
  - The A (for amino acid) site
- The large ribosomal subunit has enzyme activity that creates a peptide bond between adjacent amino acids.
  - The peptide bond is created many times to produce a polypeptide which folds into its three-dimensional shape and becomes a protein.

Ribosome Structure and Function



a. Structure of a ribosome

b. Binding sites of ribosome

c. Function of ribosomes

d. Polyribosome

d: © Science Source

Jump to Ribosome Structure and Function Long Description

Summary of Gene Expression (1)