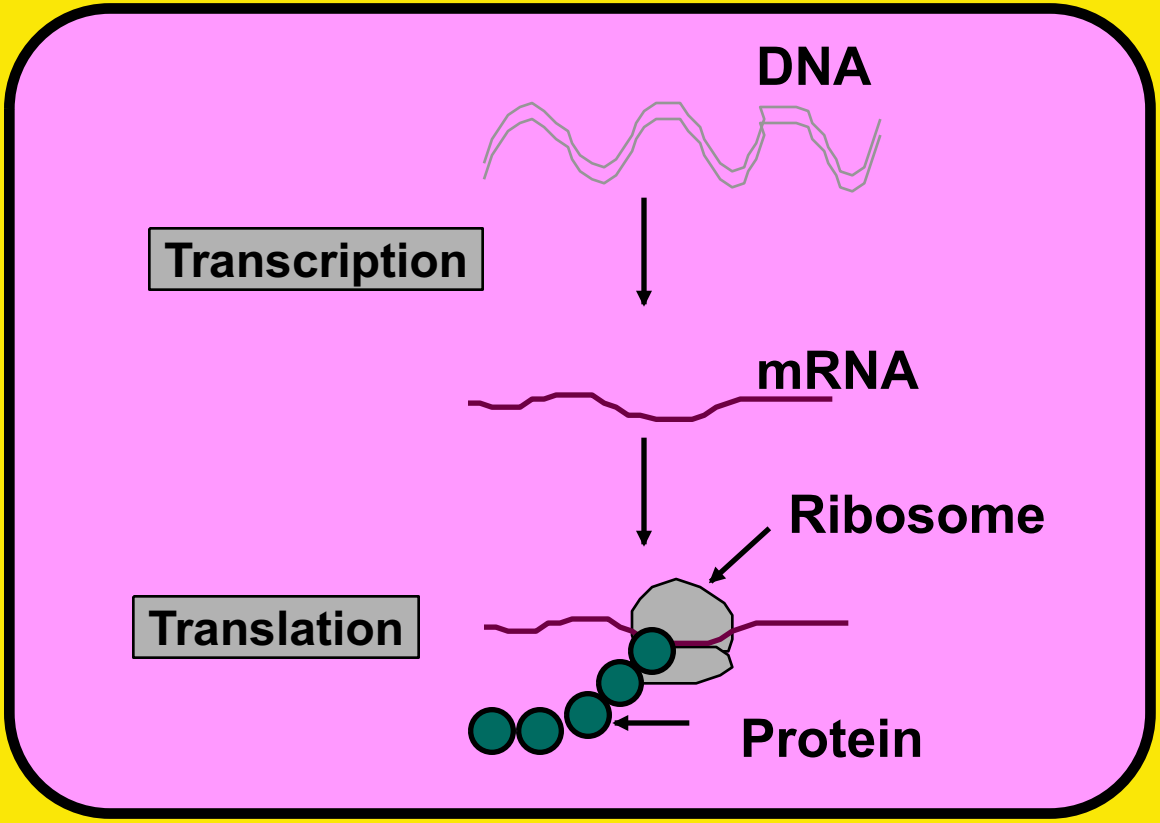
PROTEIN SYNTHESIS

Protein Synthesis

- The production (synthesis) of polypeptide chains (proteins)
- Two phases: Transcription & Translation
- mRNA must be processed before it leaves the nucleus of eukaryotic cells

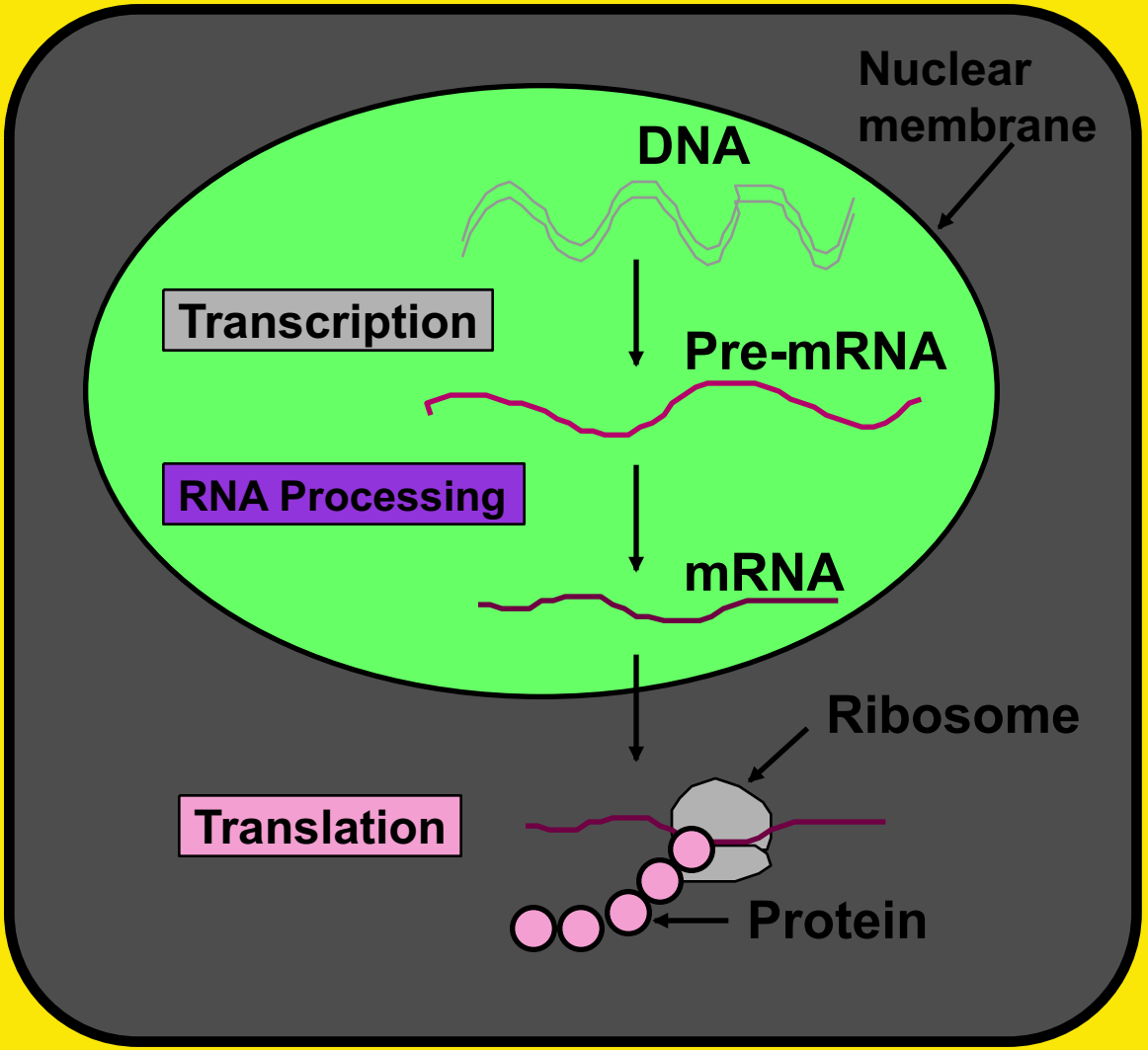
DNA → RNA → Protein



Prokaryotic Cell

DNA → RNA → Protein

Eukaryotic Cell



Pathway to Making a Protein

DNA

↓

mRNA

↓

tRNA (ribosomes)

↓

Protein

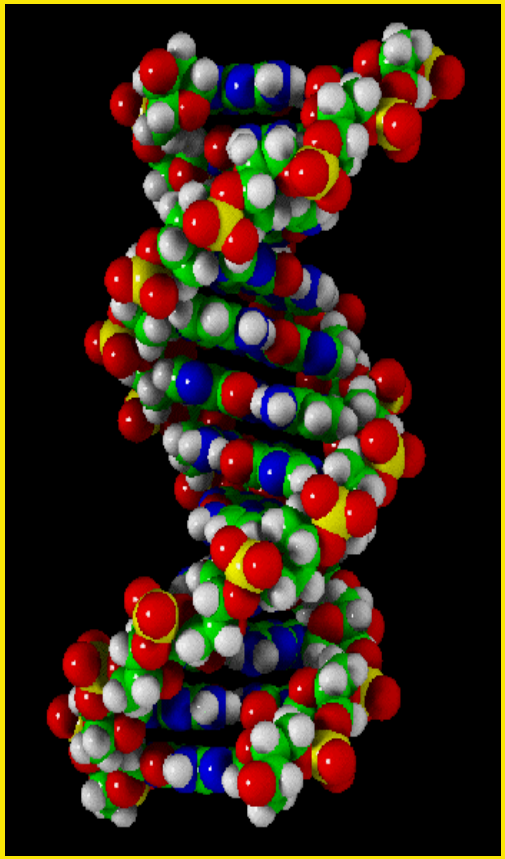
Nucleic Acids

DNA or Protein?

- Walter Sutton discovered chromosomes were made of DNA and Protein
- However, scientists were NOT sure which one (protein or DNA) was the actual genetic material of the cell

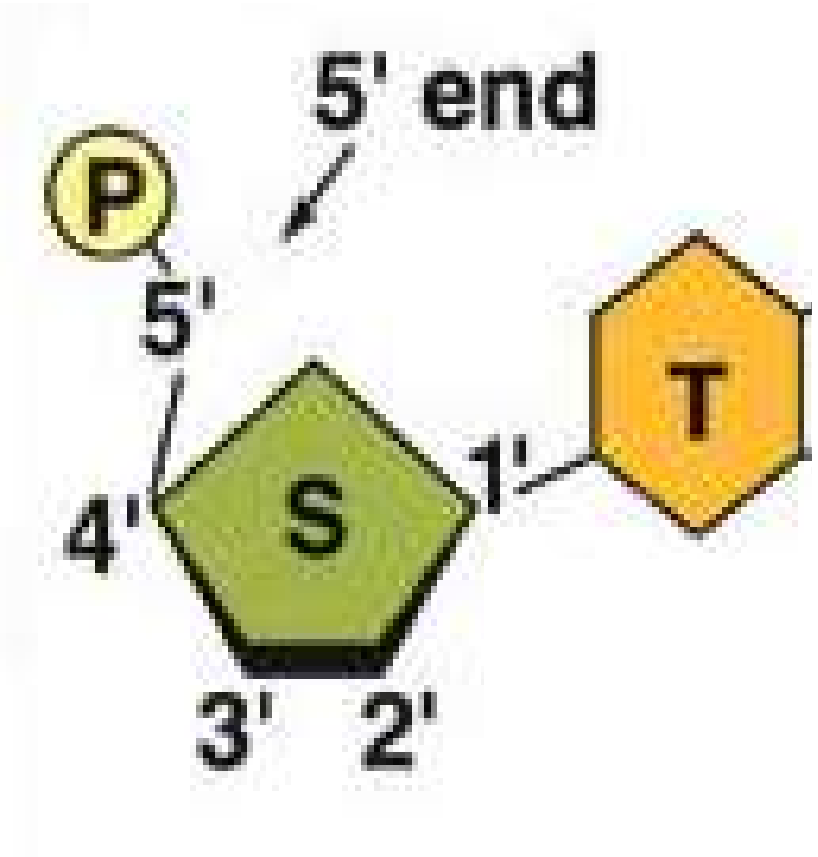
DNA!

- Frederick Griffith in 1928 showed the DNA was the cell's genetic material
- Watson & Crick in the 1950's built the 1st model of DNA



Structure of DNA

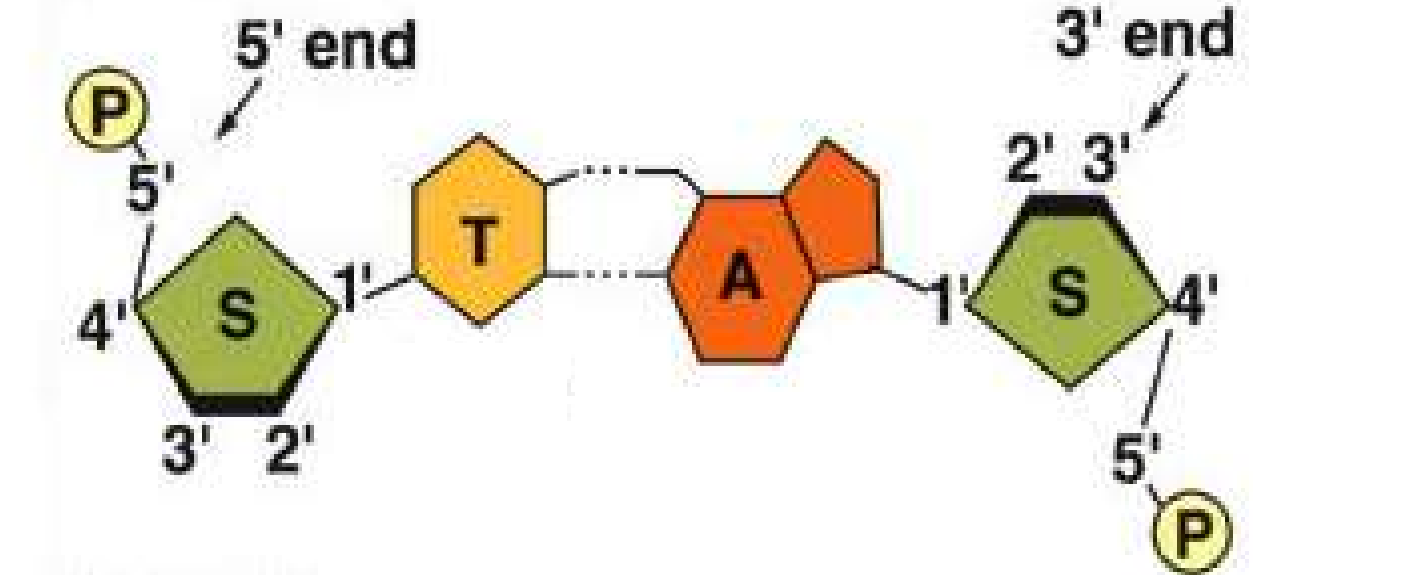
- DNA is made of subunits called nucleotides
- DNA nucleotides are composed of a phosphate, deoxyribose sugar, and a nitrogen-containing base
- The 4 bases in DNA are: adenine (A), thymine (T), guanine (G), and cytosine (C)



DNA Nucleotide

Base Pairing Rule

- Watson and Crick showed that DNA is a *double helix*
- *A* (adenine) pairs with *T* (thymine)
- *C* (cytosine) pairs with *G* (guanine)



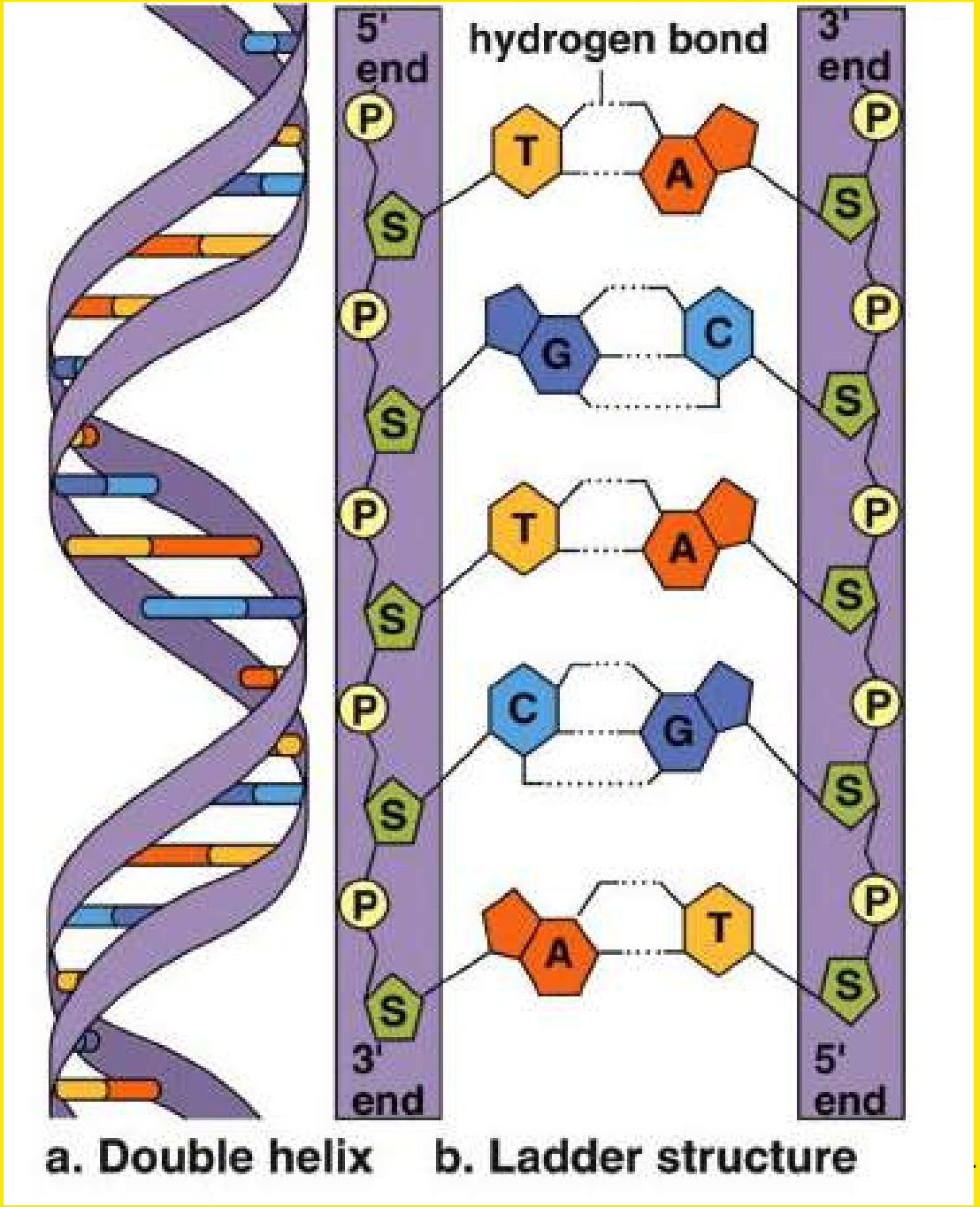
Nitrogen Rings

- Purines have single rings of carbon-nitrogen (G, A)
- Pyrimidines have double carbon-nitrogen rings (C, T)
- This is called *complementary base pairing* because a purine is always paired with a pyrimidine

5' to 3' Sugars

- When the DNA double helix unwinds, it resembles a ladder
- The sides of the ladder are the sugar-phosphate backbones
- The rungs of the ladder are the complementary paired bases
- The two DNA strands are anti-parallel (they run in opposite directions)

Anti-Parallel Strands of DNA

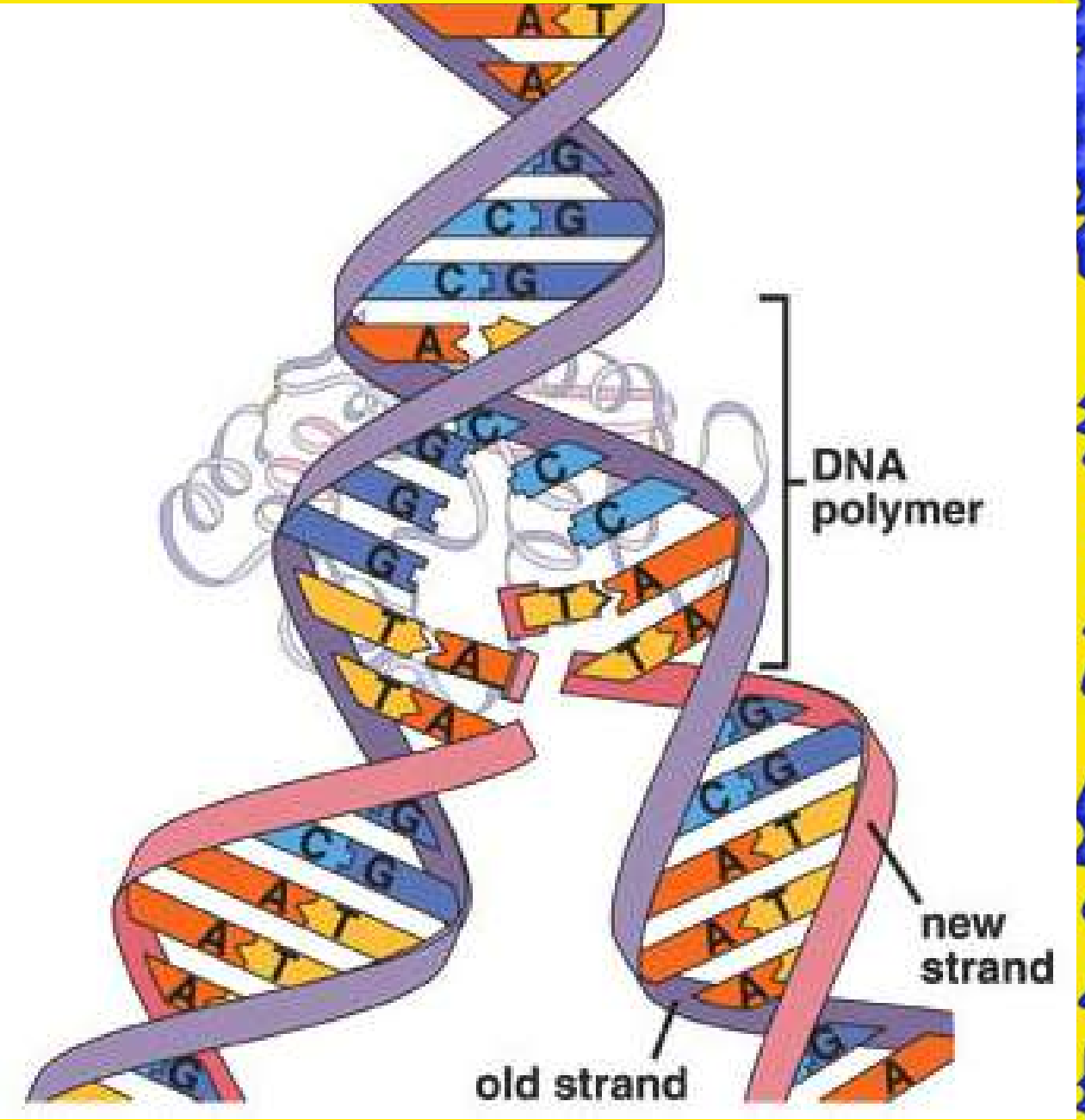


DNA Replication

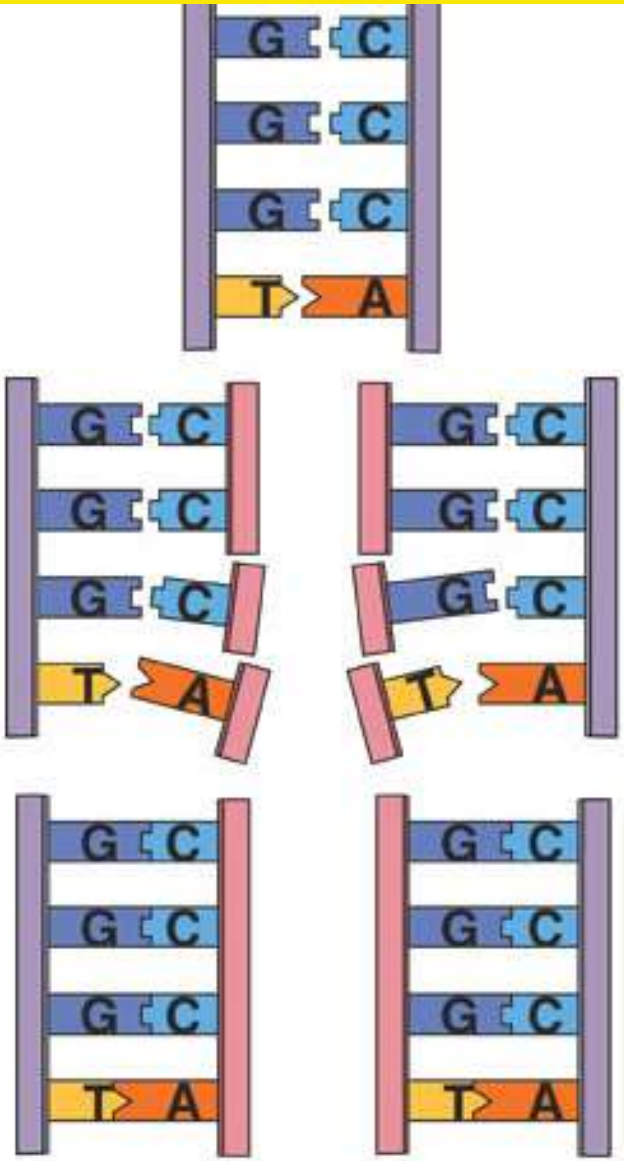
Steps in DNA Replication

- Occurs when chromosomes duplicate (make copies)
- An exact copy of the DNA is produced with the aid of the enzyme DNA polymerase
- Hydrogen bonds between bases break and enzymes "unzip" the molecule
- Each old strand of nucleotides serves as a template for each new strand
- New nucleotides move into complementary positions are joined by DNA polymerase

Two New, Identical DNA Strands Result from Replication



Another View of Replication



Parental DNA molecule contains so-called old strands hydrogen-bonded by complementary base pairing.

Region of replication. Parental DNA is unwound and unzipped. New nucleotides are pairing with those in old strands.

Replication is complete. Each double helix is composed of an old (parental) strand and a new (daughter) strand.

RNA

RNA Differs from DNA

1. RNA has a sugar ribose

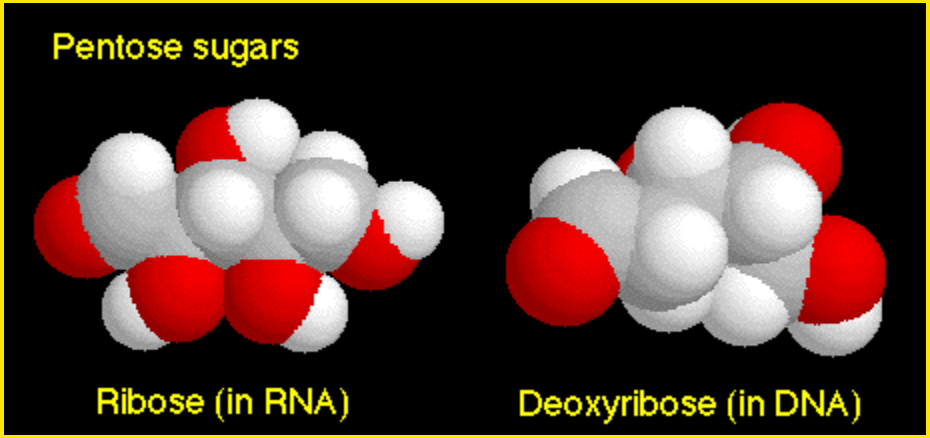
DNA has a sugar deoxyribose

2. RNA contains the base uracil (U)

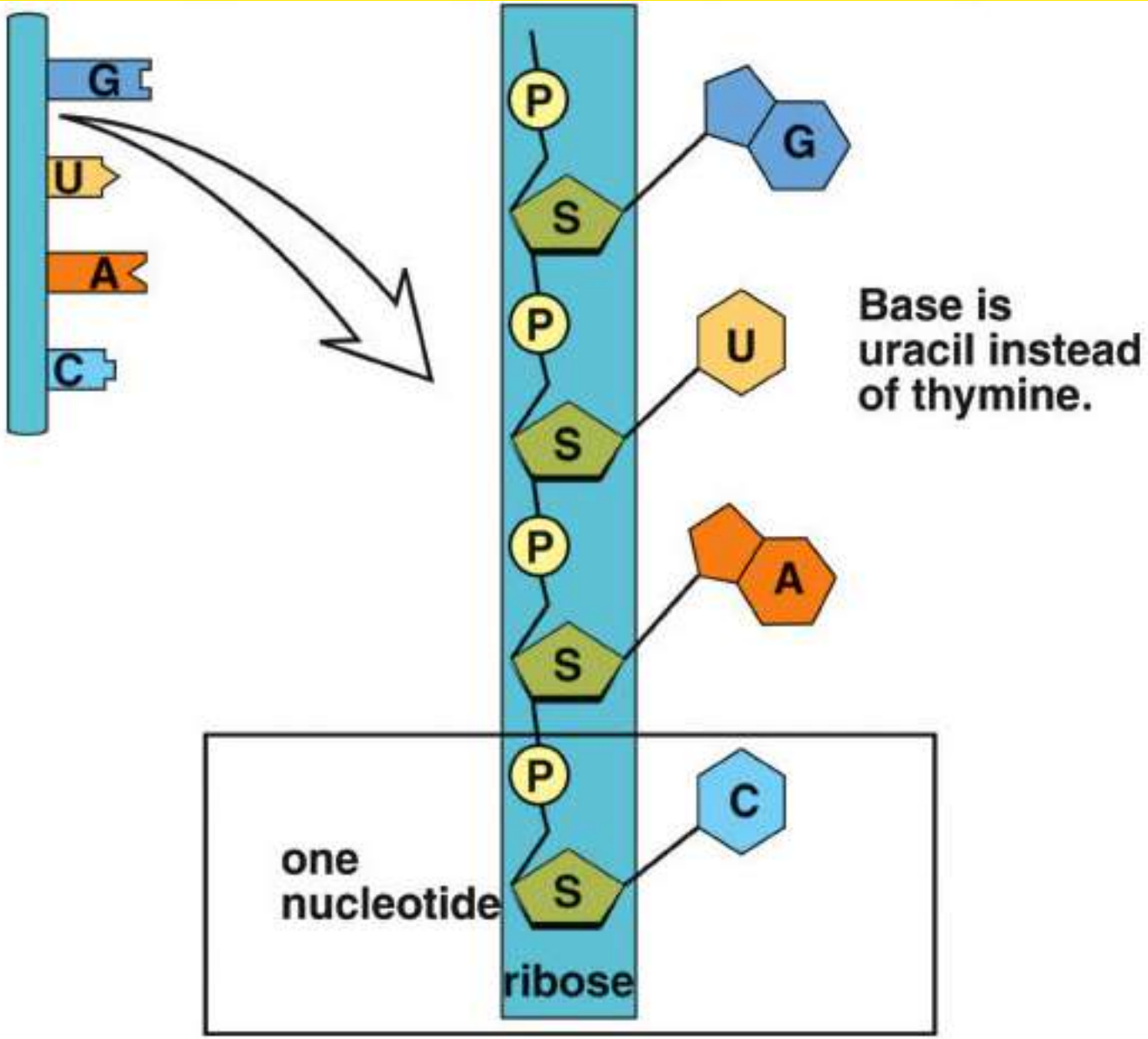
DNA has thymine (T)

3. RNA molecule is single-stranded

DNA is double-stranded



Structure of RNA



Three Types of RNA

- Messenger RNA (mRNA) carries genetic information to the ribosomes
- Ribosomal RNA (rRNA), along with protein, makes up the ribosomes
- Transfer RNA (tRNA) transfers amino acids to the ribosomes where proteins are synthesized

Making a Protein

Genes & Proteins

- Proteins are made of amino acids linked together by peptide bonds
- 20 different amino acids exist
- Amino acids chains are called polypeptides
- Segment of DNA that codes for the amino acid sequence in a protein are called genes

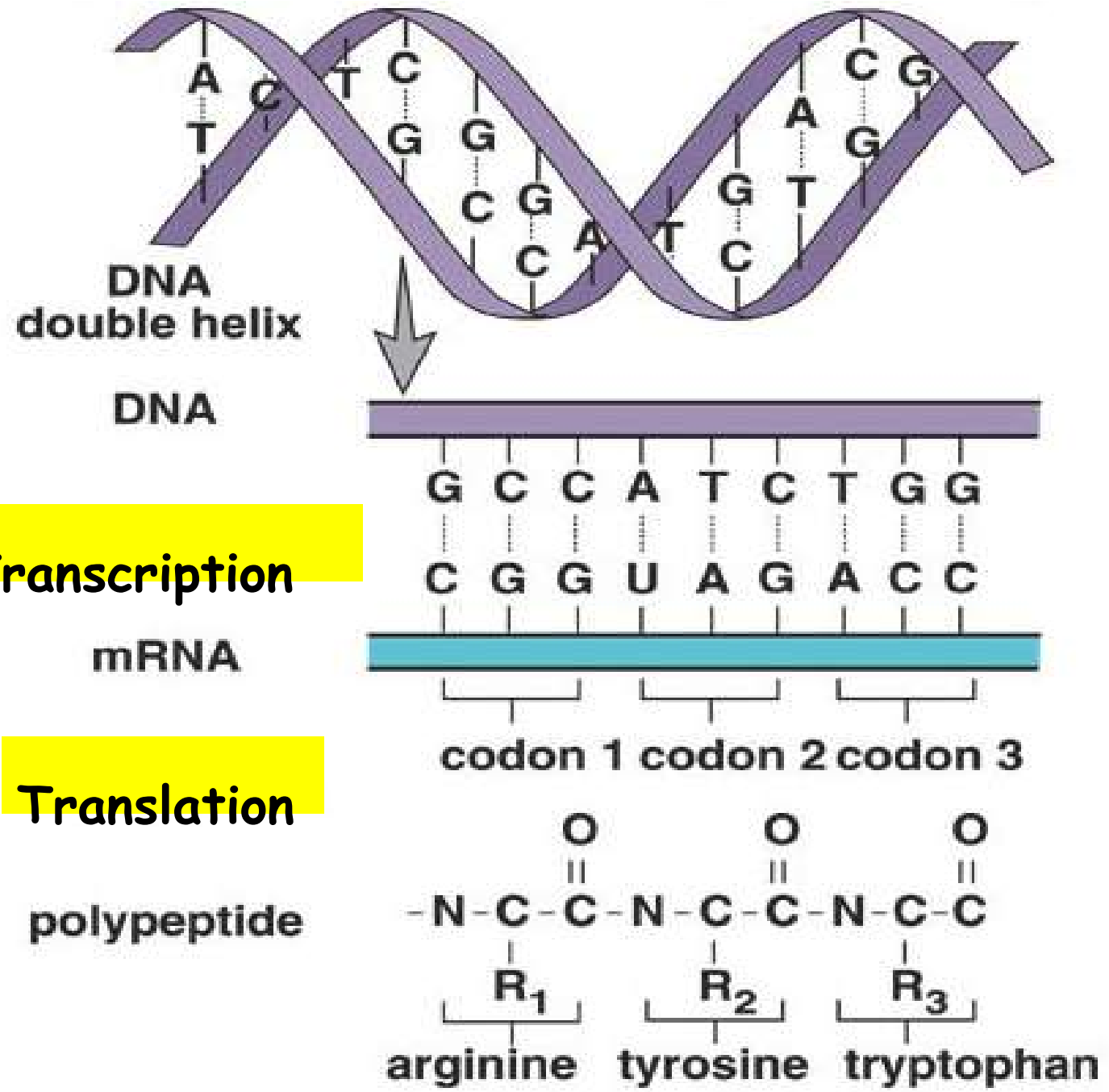
Two Parts of Protein Synthesis

- *Transcription* makes an RNA molecule complementary to a portion of DNA
- *Translation* occurs when the sequence of bases of mRNA DIRECTS the sequence of amino acids in a polypeptide

Genetic Code

- DNA contains a triplet code
- Every three bases on DNA stands for ONE amino acid
- Each three-letter unit on mRNA is called a codon
- Most amino acids have more than one codon!
- There are 20 amino acids with a possible 64 different triplets
- The code is nearly universal among living organisms

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


DNA
double helix
DNA
G C C A T C T G G
C G G U A G A C C
mRNA
codon 1 codon 2 codon 3
Transcription
Translation
polypeptide
O O O
N C C N C C N C C
R1 R2 R3
arginine tyrosine tryptophan

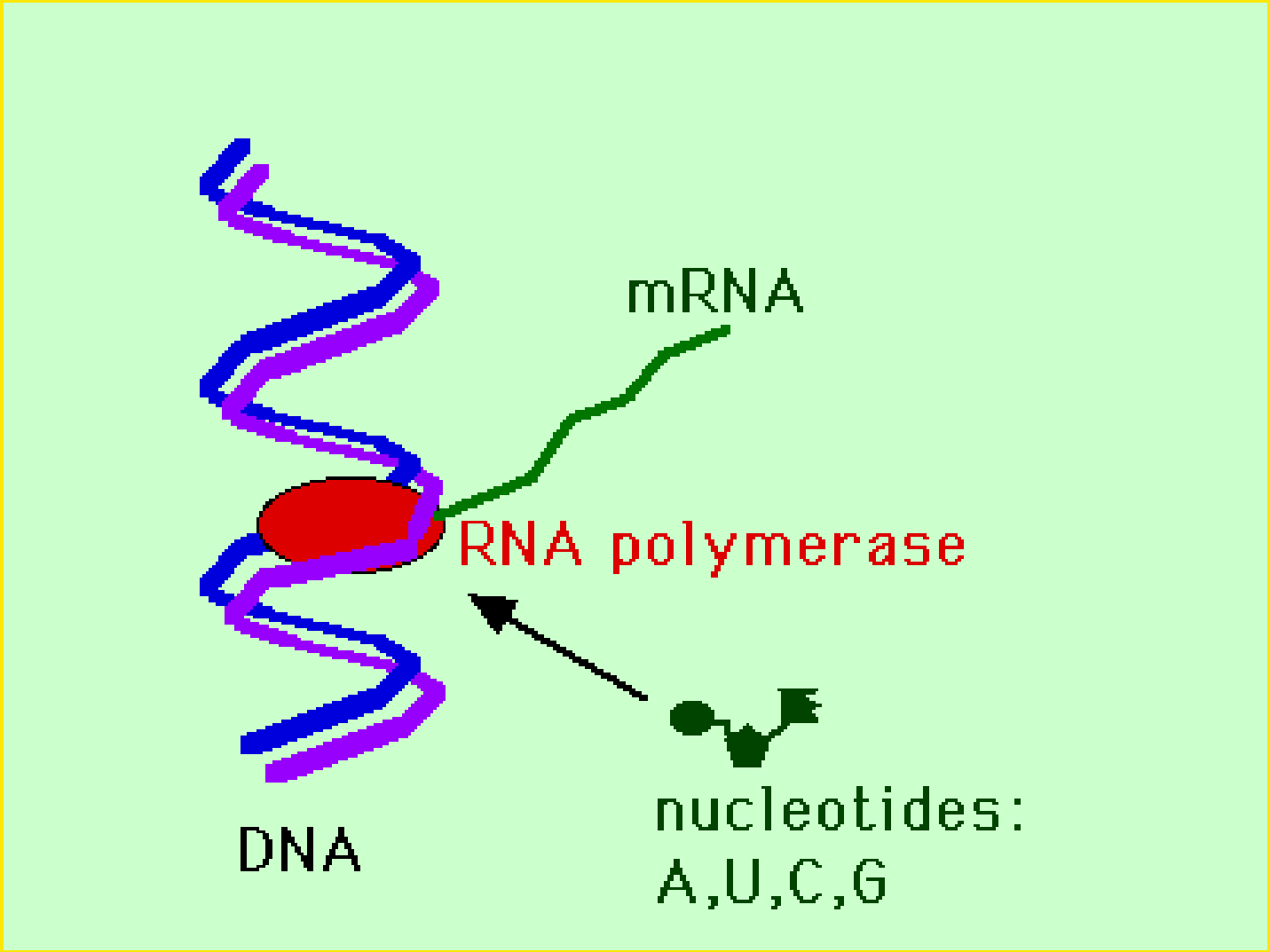
Overview of Transcription

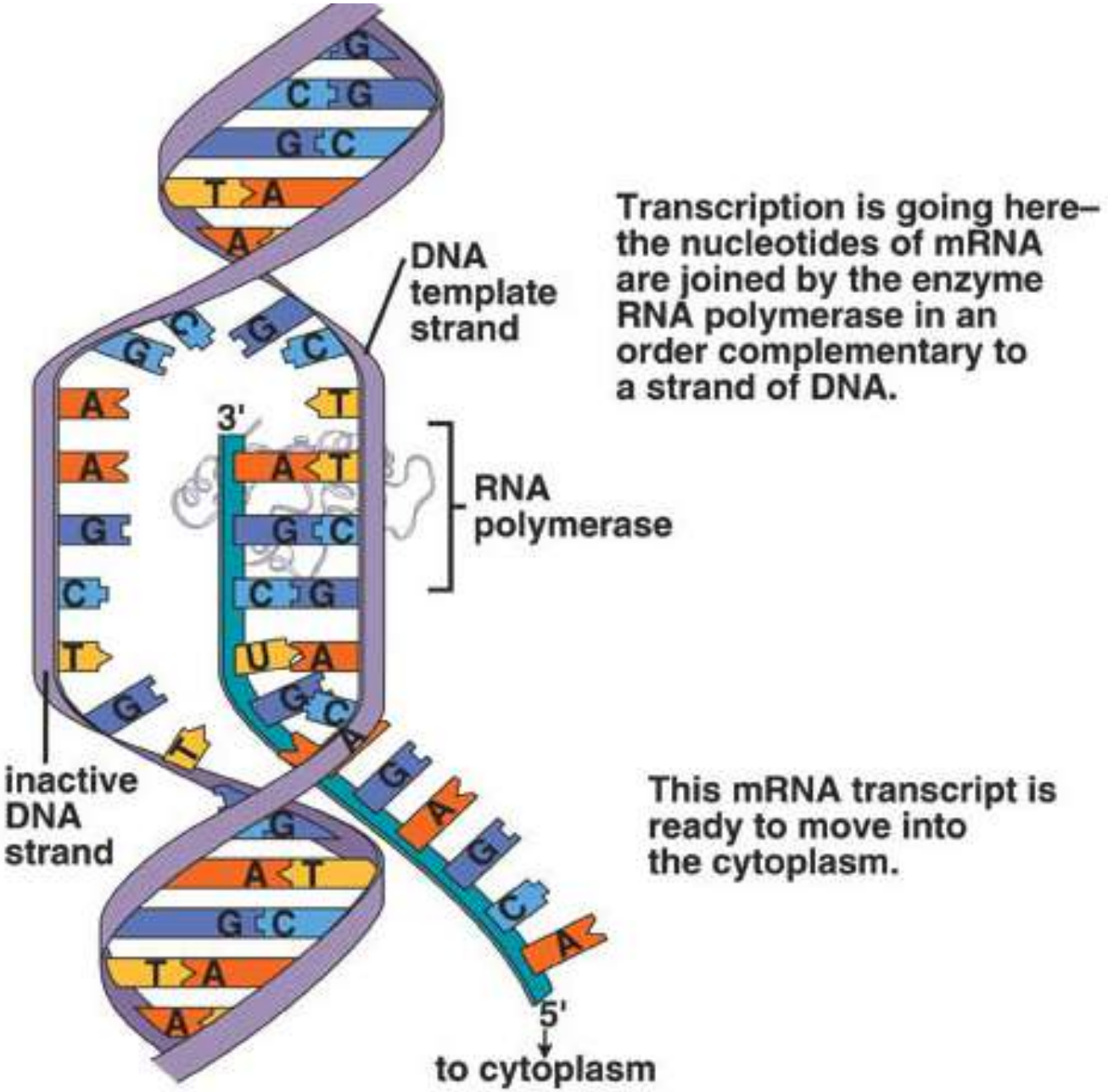
- During transcription in the nucleus, a segment of DNA unwinds and unzips, and the DNA serves as a template for mRNA formation
- RNA polymerase joins the RNA nucleotides so that the codons in mRNA are complementary to the triplet code in DNA

Steps in Transcription

- The transfer of information in the nucleus from a DNA molecule to an RNA molecule
- Only 1 DNA strand serves as the template
- Starts at promoter DNA (TATA box)
- Ends at terminator DNA (stop)
- When complete, pre-RNA molecule is released

Transcription

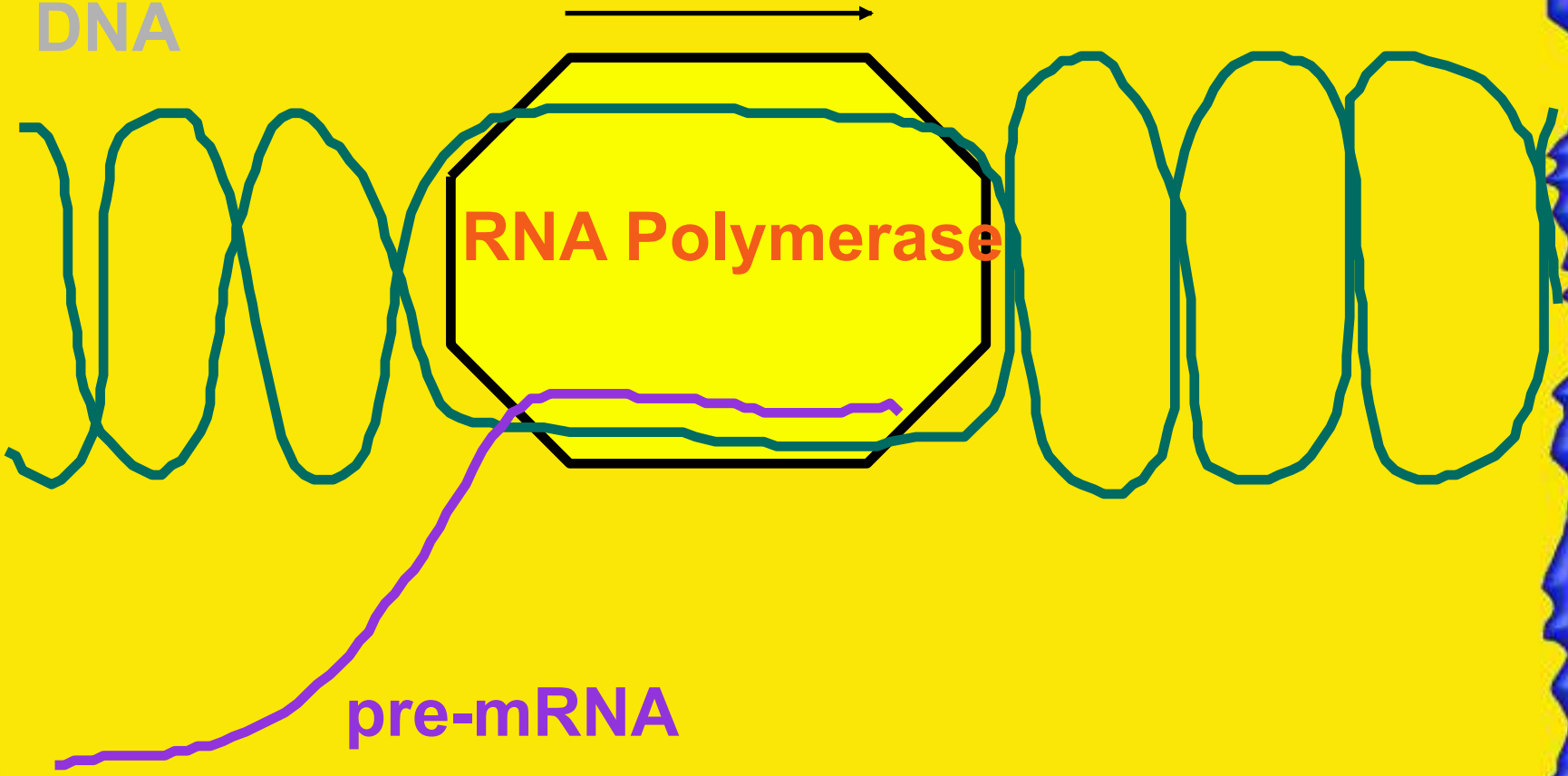



DNA
template
strand
Transcription is going here–
the nucleotides of mRNA
are joined by the enzyme
RNA polymerase in an
order complementary to
a strand of DNA.
3'
RNA
polymerase
inactive
DNA
strand
This mRNA transcript is
ready to move into
the cytoplasm.
5'
to cytoplasm

What is the enzyme responsible for the production of the mRNA molecule?

RNA Polymerase

- Enzyme found in the nucleus
- Separates the two DNA strands by breaking the hydrogen bonds between the bases
- Then moves along one of the DNA strands and links RNA nucleotides together


DNA
RNA Polymerase
pre-mRNA

Question:

- What would be the complementary RNA strand for the following DNA sequence?

DNA 5'-GCGTATG-3'

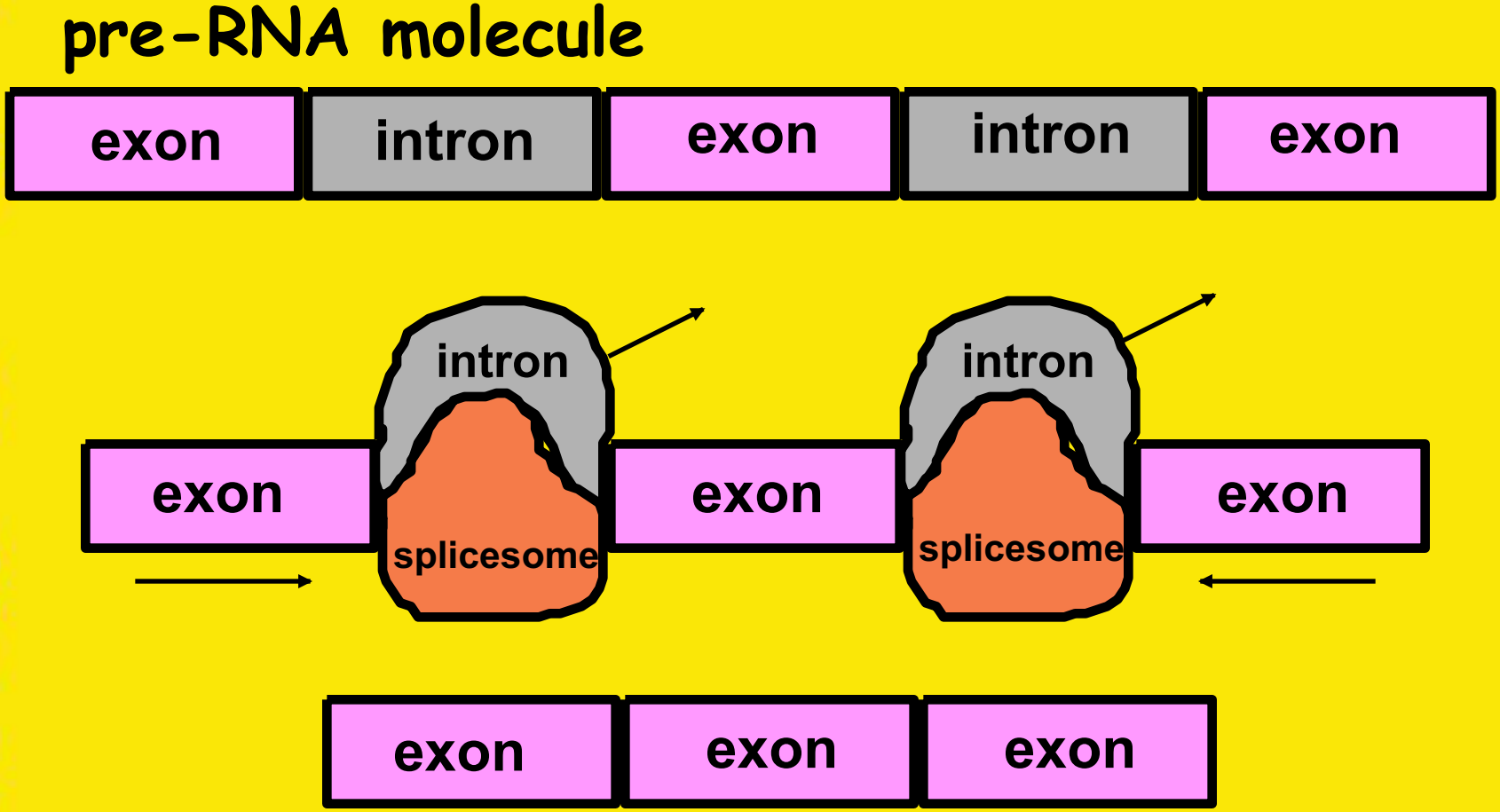
Answer:

- DNA 5'-GCGTATG-3'
- RNA 3'-CGCAUAC-5'

Processing Pre-mRNA

- Also occurs in the nucleus
- Pre-mRNA made up of segments called introns & exons
- Exons code for proteins, while introns do NOT!
- Introns spliced out by splicesome-enzyme and exons re-join
- End product is a mature RNA molecule that leaves the nucleus to the cytoplasm

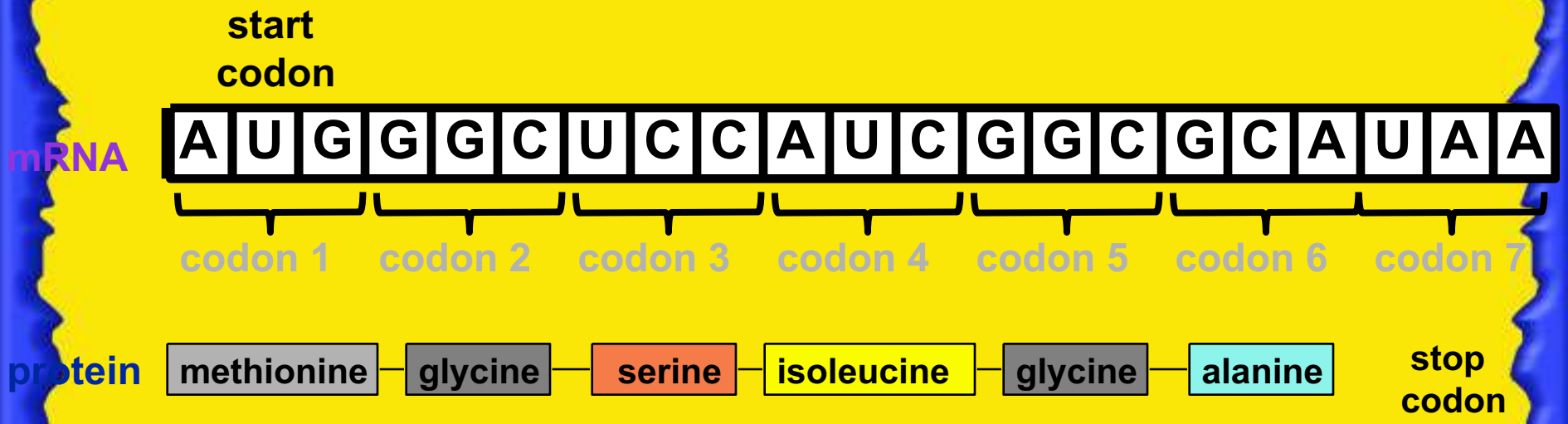
RNA Processing



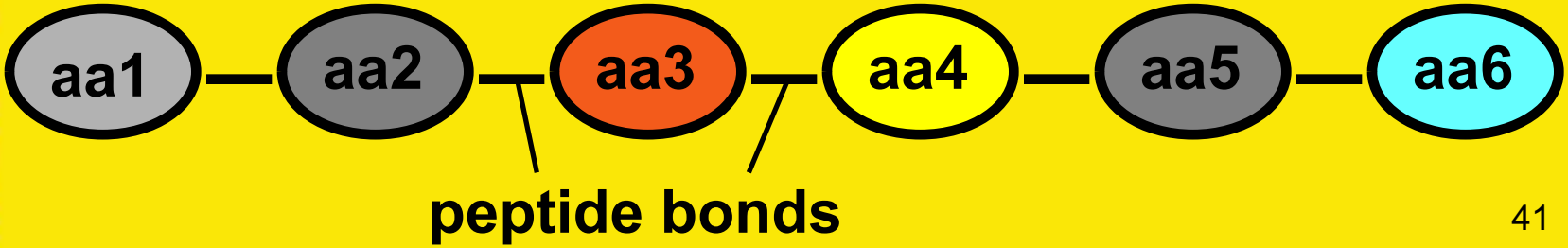
Messenger RNA (mRNA)

- Carries the information for a specific protein
- Made up of 500 to 1000 nucleotides long
- Sequence of 3 bases called codon
- AUG – methionine or start codon
- UAA, UAG, or UGA – stop codons

Messenger RNA (mRNA)



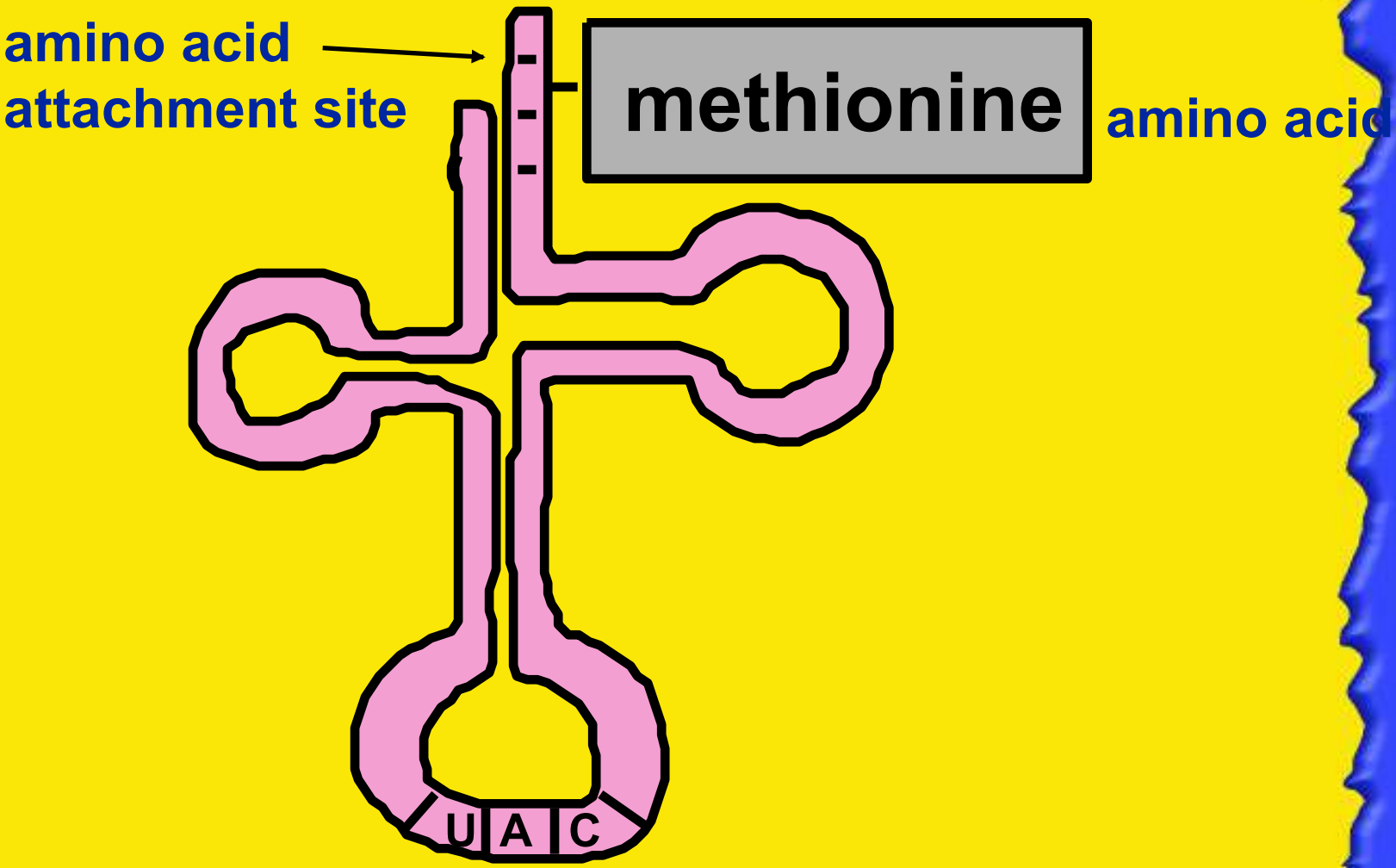
Primary structure of a protein



Transfer RNA (tRNA)

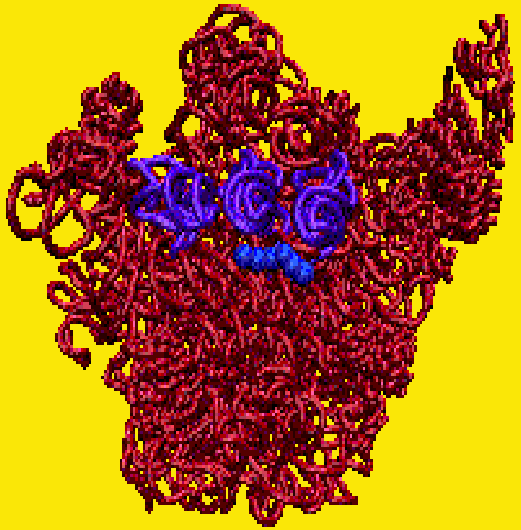
- Made up of 75 to 80 nucleotides long
- Picks up the appropriate amino acid floating in the cytoplasm
- Transports amino acids to the mRNA
- Have anticodons that are complementary to mRNA codons
- Recognizes the appropriate codons on the mRNA and bonds to them with H-bonds

Transfer RNA (tRNA)



Ribosomal RNA (rRNA)

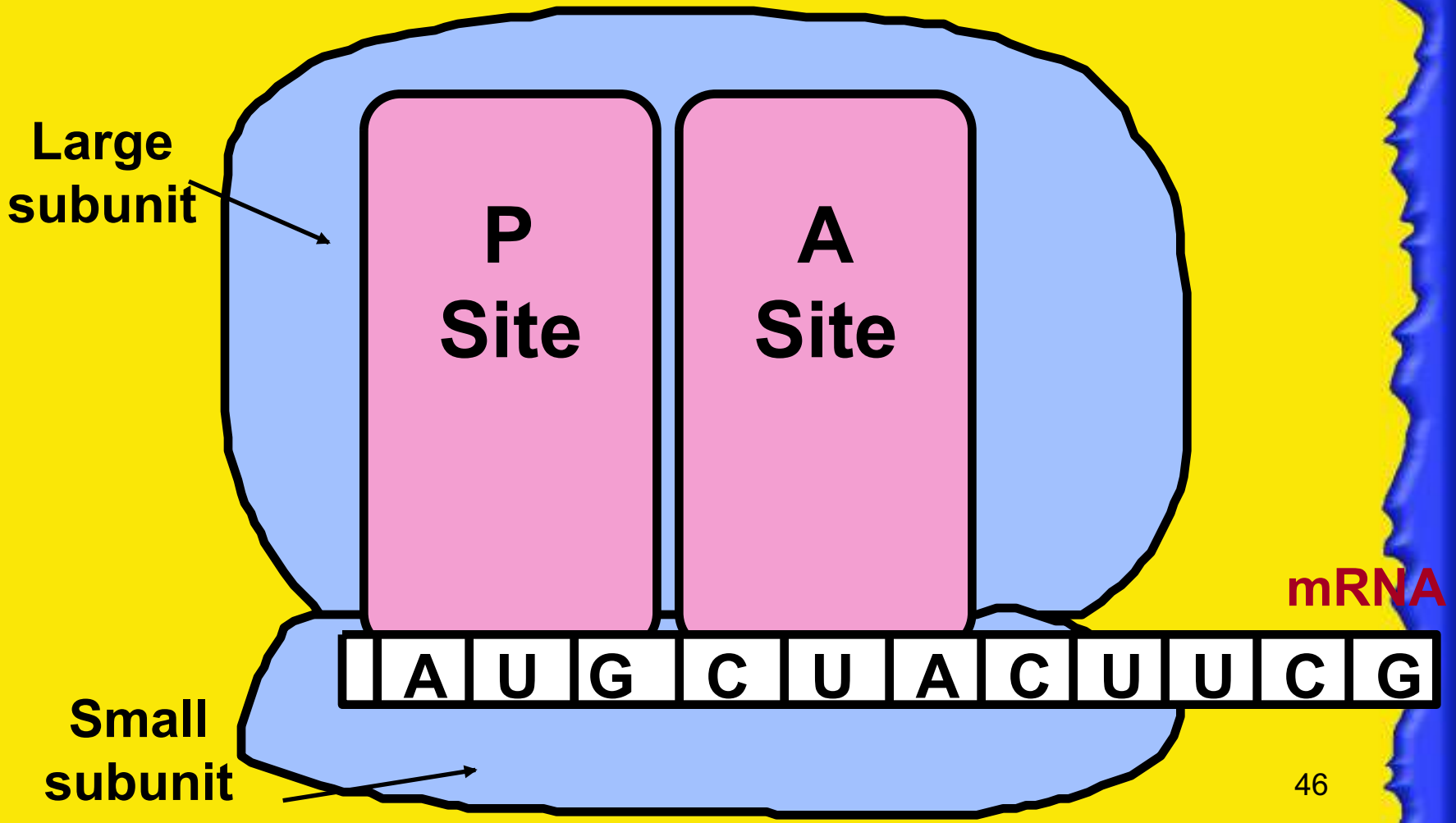
- Made up of rRNA is 100 to 3000 nucleotides long
- Made inside the nucleus of a cell
- Associates with proteins to form ribosomes



Ribosomes

- Made of a large and small subunit
- Composed of rRNA (40%) and proteins (60%)
- Have two sites for tRNA attachment --- P and A

Ribosomes



Translation

- Synthesis of proteins in the cytoplasm
- Involves the following:

1. mRNA (codons)
2. tRNA (anticodons)
3. ribosomes
4. amino acids

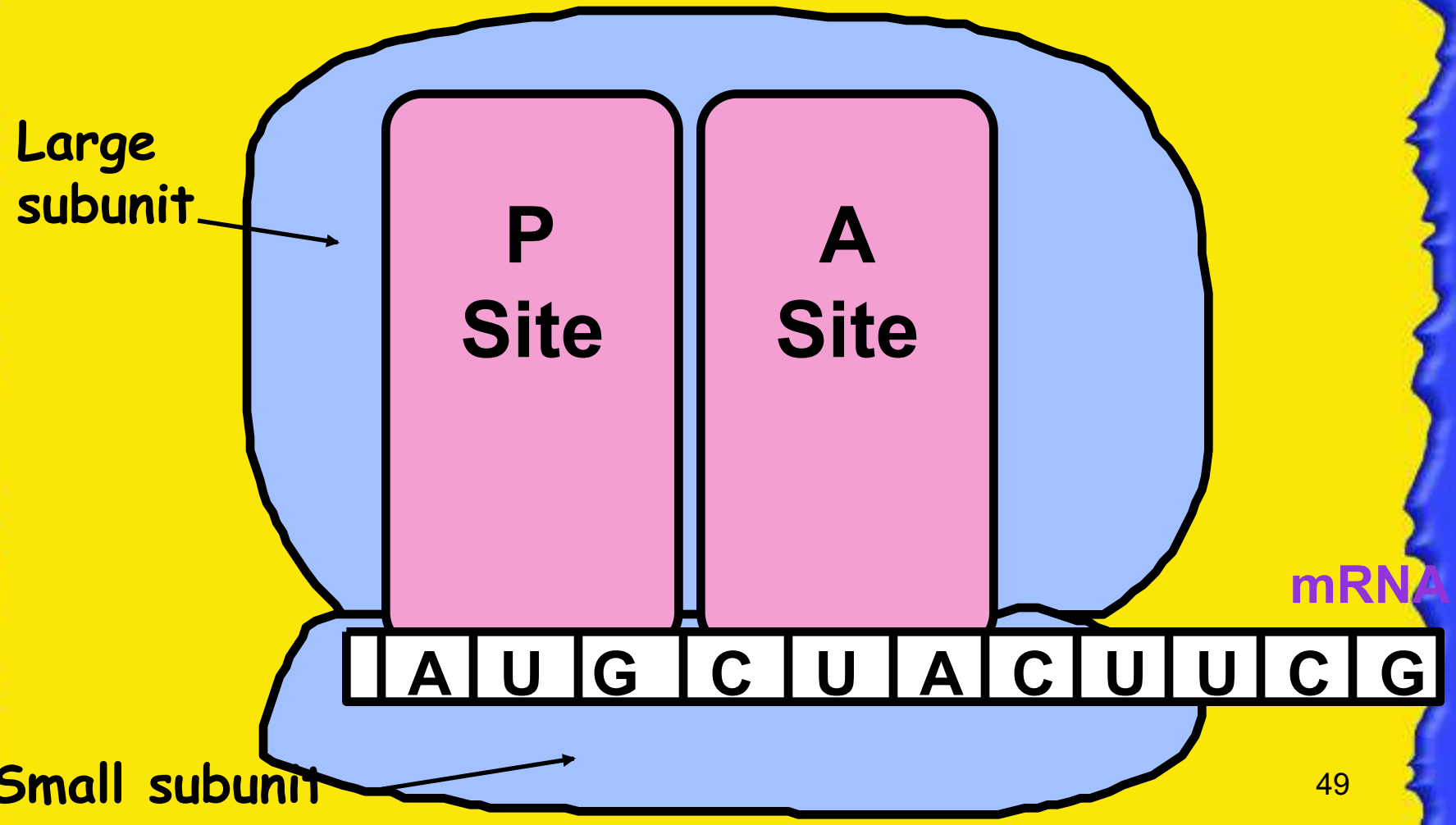
Translation

- Three steps:

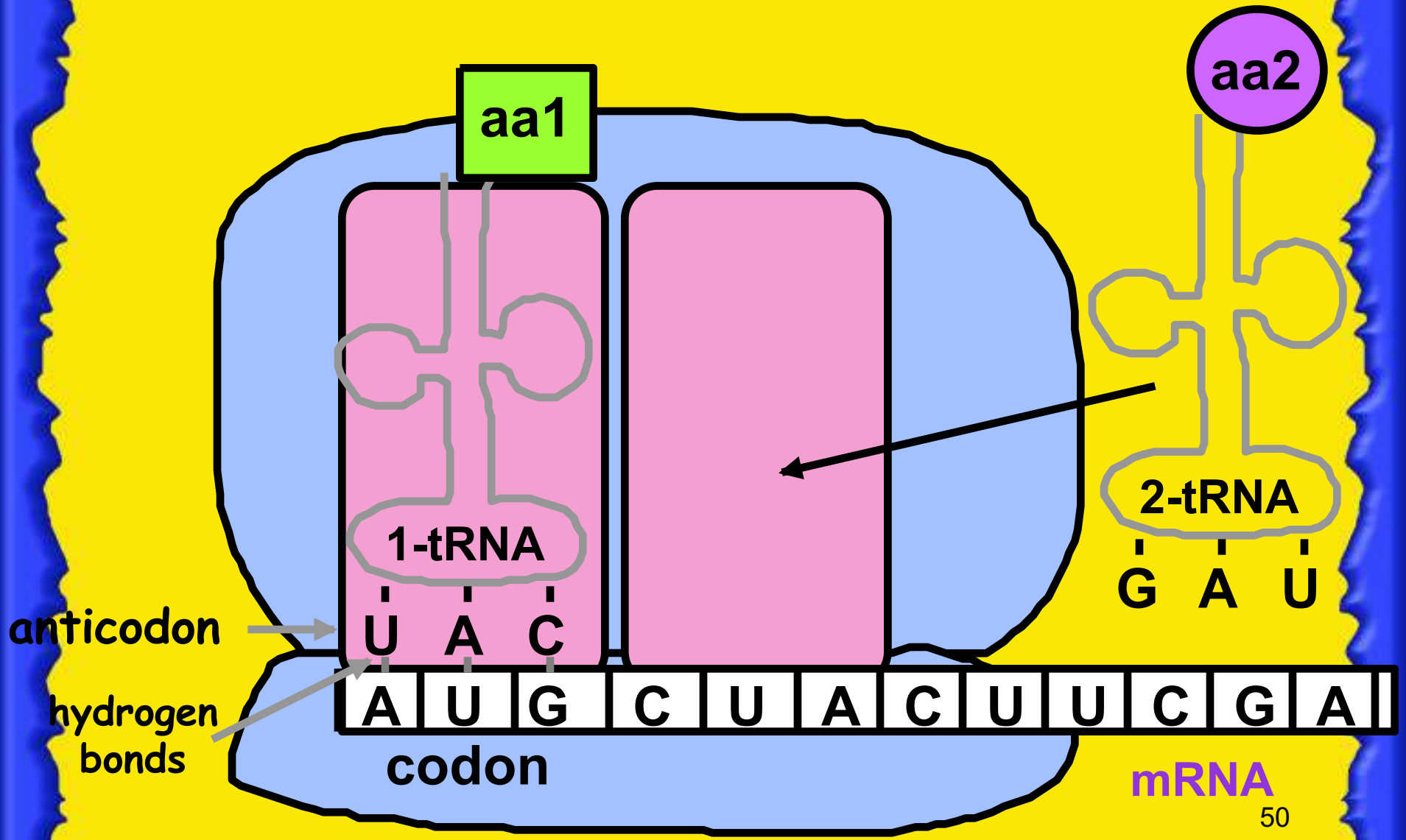
1. initiation: start codon (AUG)
2. elongation: amino acids linked
3. termination: stop codon (UAG, UAA, or UGA).

Let's Make a Protein !

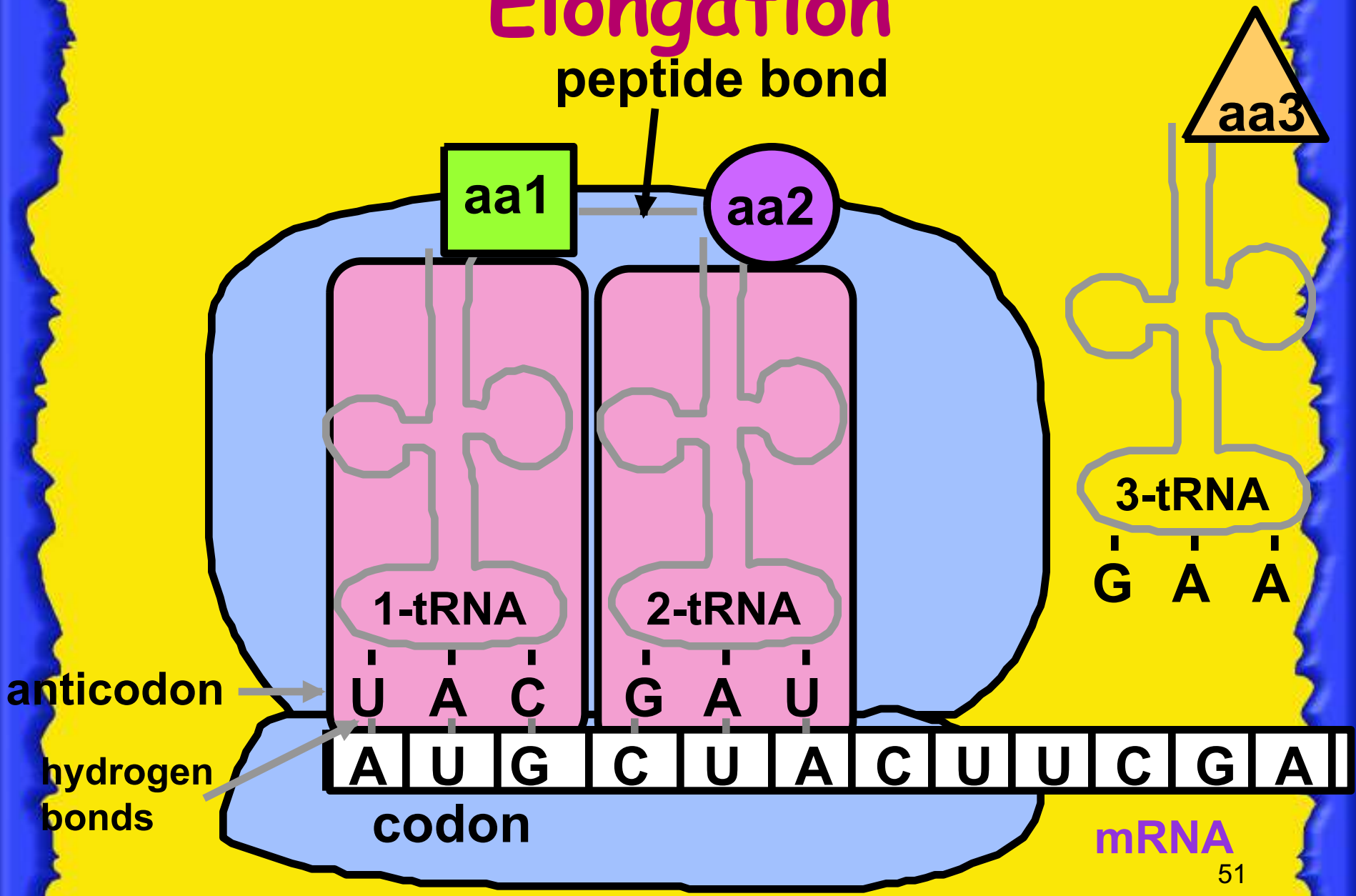
mRNA Codons Join the Ribosome

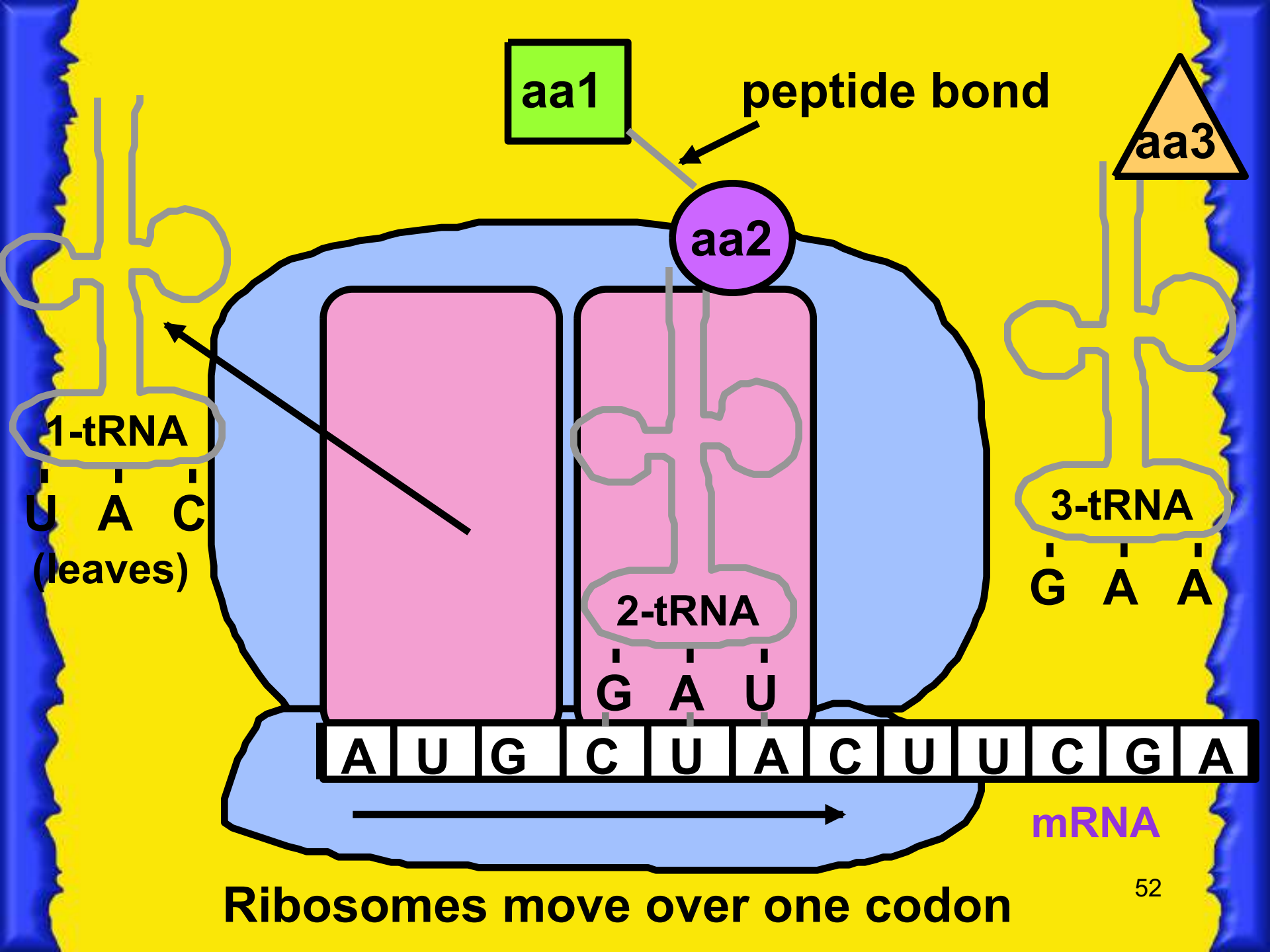


Initiation

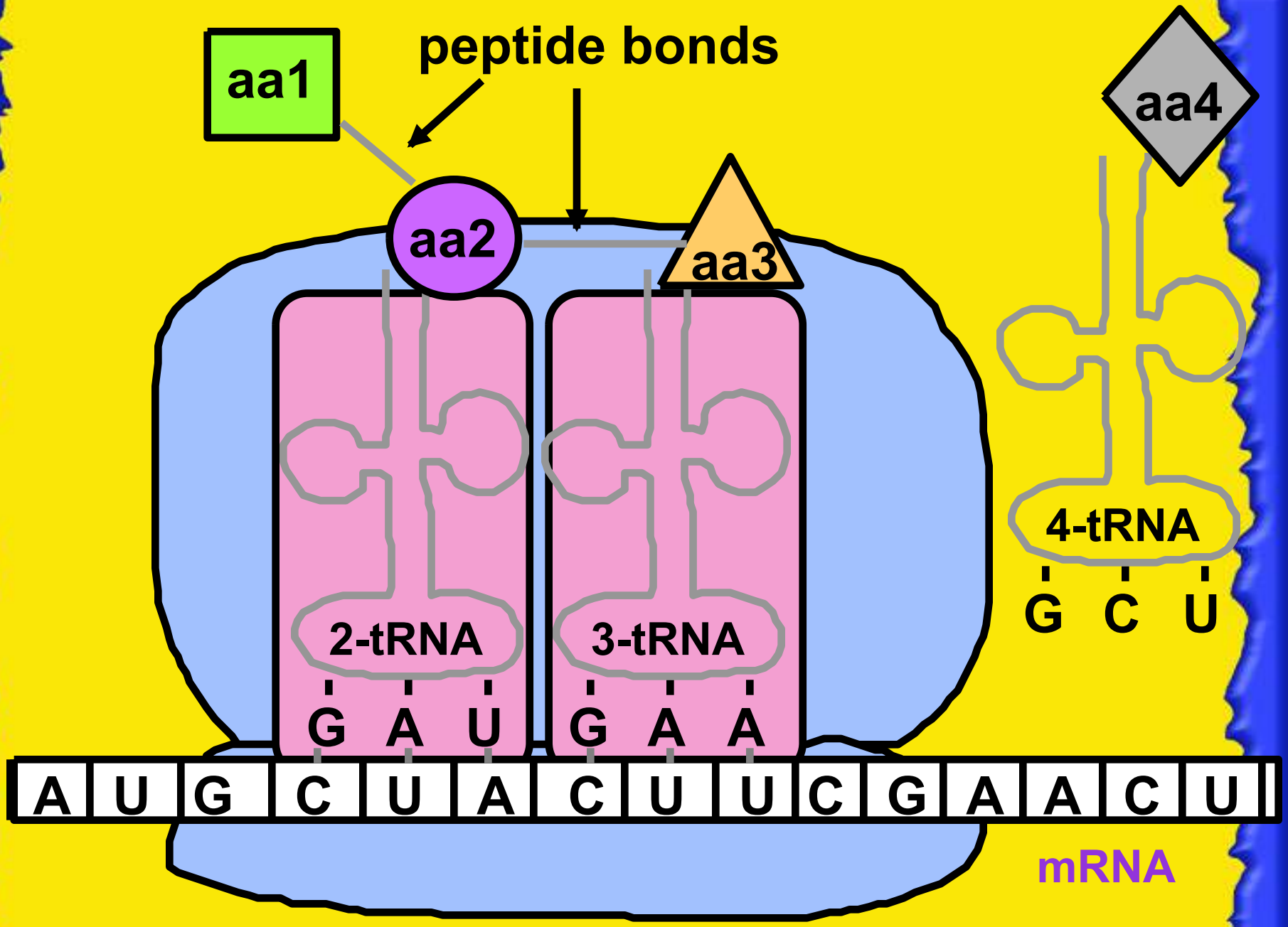

aa2
aa1
2-tRNA
G A U
1-tRNA
U A C
anticodon
hydrogen bonds
A U G C U A C U U C G A
codon
mRNA

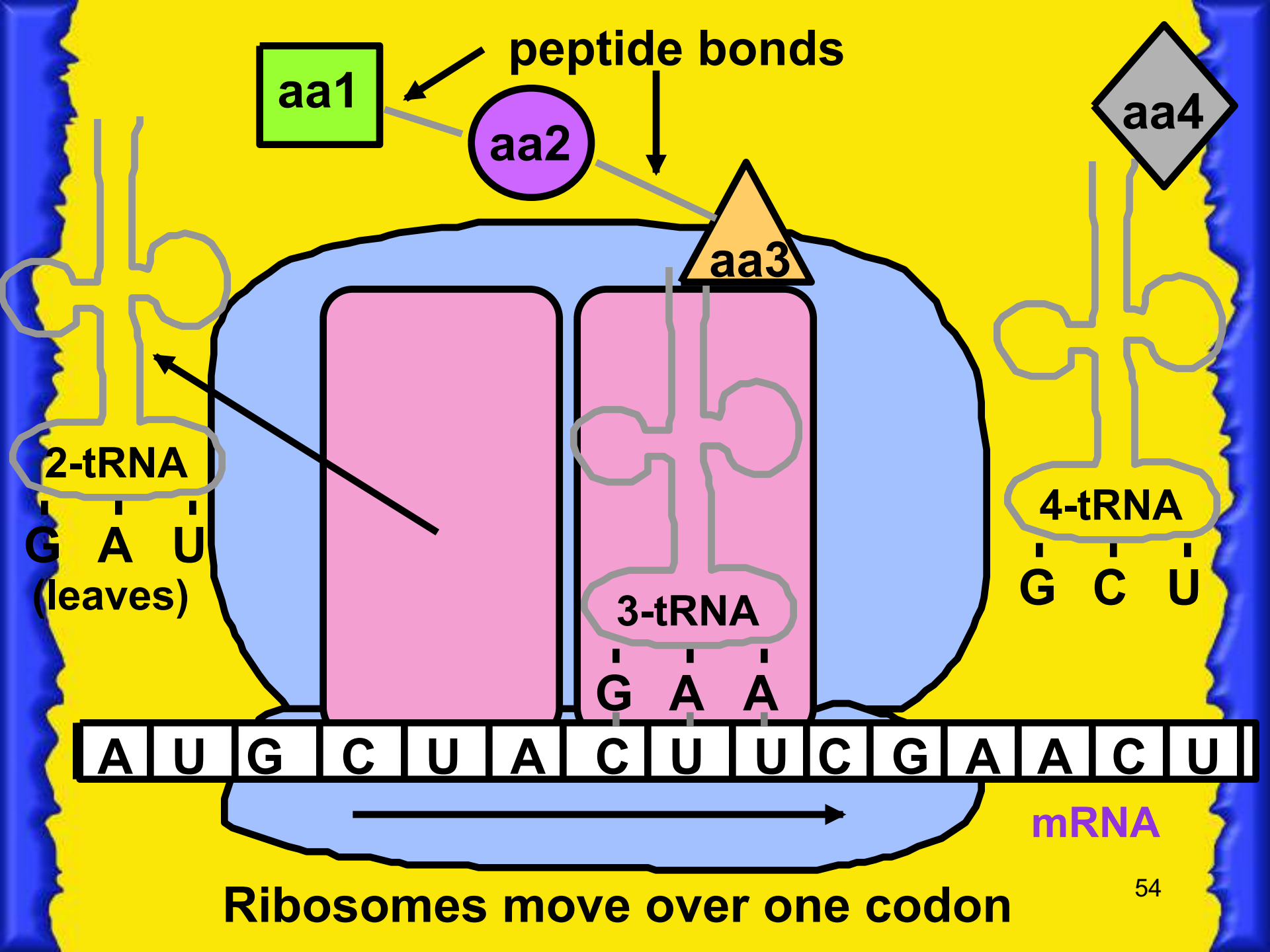
Elongation

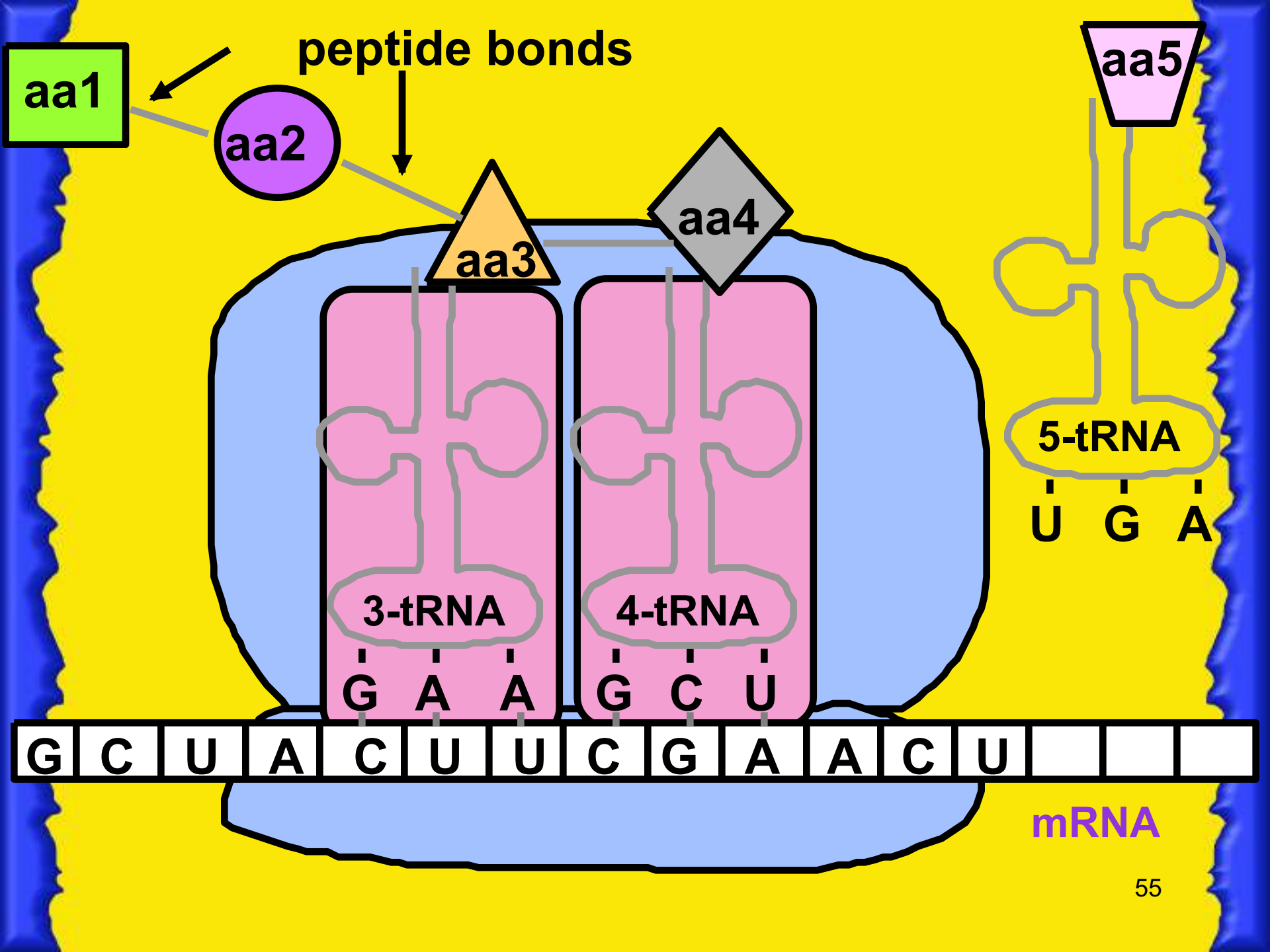

peptide bond
aa1
aa2
aa3
1-tRNA
2-tRNA
3-tRNA
G A A
anticodon
U A C
G A U
hydrogen bonds
A U G C U A C U U C G A
codon
mRNA

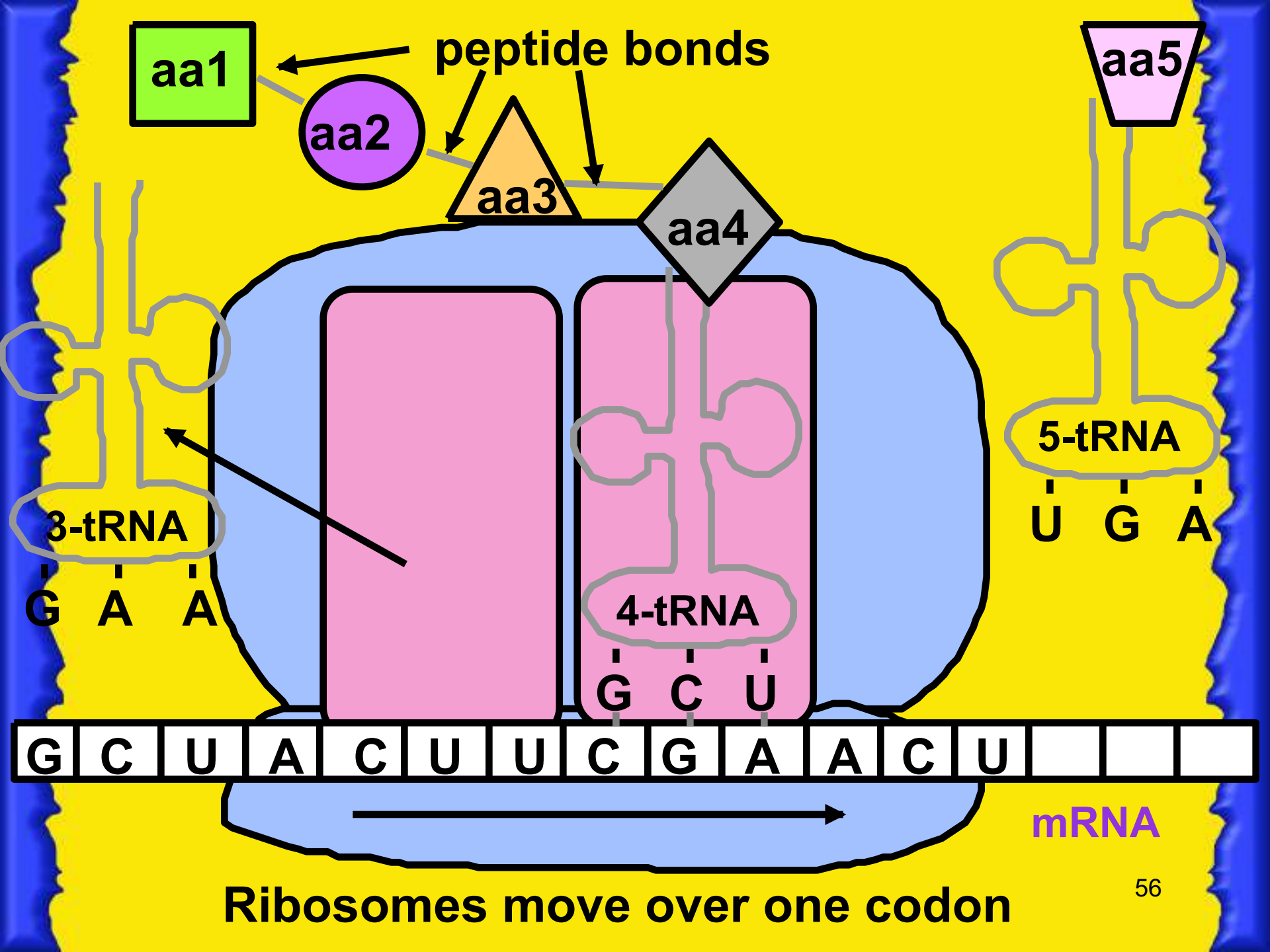


Ribosomes move over one codon


aa1
peptide bonds
aa4
aa2
aa3
4-tRNA
G C U
2-tRNA
3-tRNA
G A U
G A A
A U G C U A C U U C G A A C U
mRNA

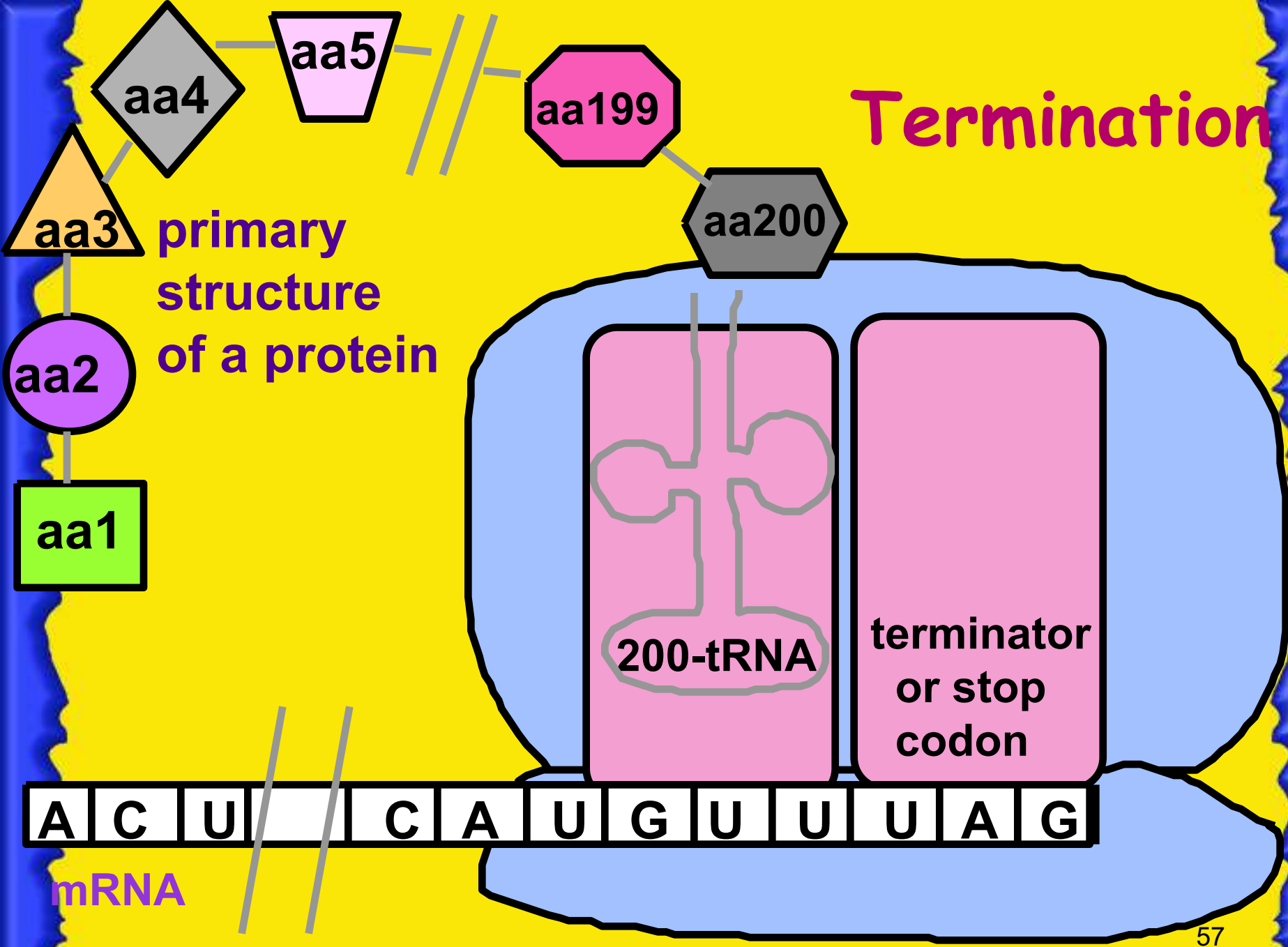

peptide bonds
aa1
aa2
aa3
aa4
2-tRNA
G A U
(leaves)
3-tRNA
G A A
4-tRNA
G C U
A U G C U A C U U C G A A C U
mRNA
Ribosomes move over one codon


peptide bonds
aa1
aa2
aa3
aa4
aa5
5-tRNA
U G A
3-tRNA
G A A
4-tRNA
G C U
G C U A C U U C G A A C U
mRNA



Ribosomes move over one codon

Termination



End Product –The Protein!

- The end products of protein synthesis is a primary structure of a protein
- A sequence of amino acid bonded together by peptide bonds