



6.3 - Translation: Synthesizing Proteins from mRNA

Pages 257-266 (McGraw-Hill Ryerson, 2011)



Subtopics

- Overview
 - tRNA, ribosomes
- The Molecular Events of Translation
 - Initiation
 - Elongation
 - Termination
- A review of Gene Expression
- DNA Mutations and Effects of Mutagens
 - Single Gene
 - Causes
 - DNA Repair

Overview

Molecular Components of Translation

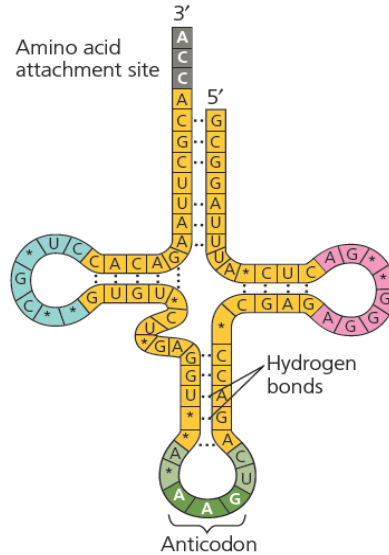
- Transfer RNA (tRNA) has the following structural features:
 - ◆ A single strand of RNA forming a 3 stem-loop structure
 - ◆ One of these loops is an **anti-codon loop** - the base pair sequence here is complementary to mRNA codons
 - ◆ One end of the single strand (3') is the **acceptor stem** - the amino acid is located here
 - ◆ **aminoacyl-tRNA synthetase** - the enzyme responsible for joining an amino acid to a specific tRNA (with a specific anti-codon)

Overview

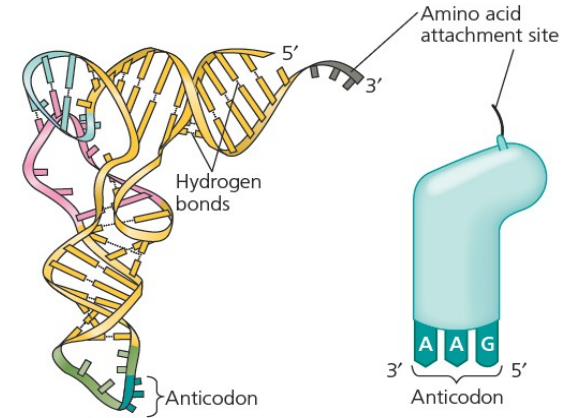
tRNA structure

→ Take special note of:

- ◆ the amino acid attachment site (acceptor stem)
- ◆ The anticodon loop



(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, as are some sequences in the other two loops. (The asterisks mark bases that have been chemically modified, a characteristic of tRNA. The modified bases contribute to tRNA function in a way that is not yet understood.)



(b) Three-dimensional structure

(c) Symbol used in this book

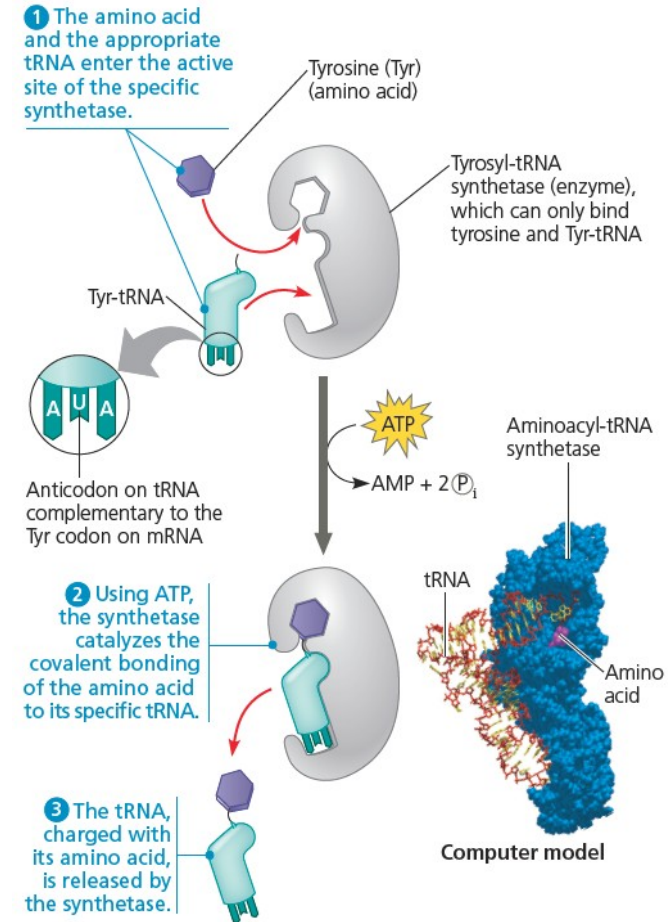
Overview

aminoacyl-tRNA synthetase

- There are 20 different enzymes which facilitate the synthesis of 20 different tRNA molecules (for each amino acid)
- So why aren't there 61 different tRNA synthetase enzymes and thus 61 different tRNAs?
 - ◆ Wobble pairing!
 - ◆ A tRNA molecule can be flexible with the third base when it interacts with an

https://www.youtube.com/watch?v=zHfiWXQIA2Q&ab_channel=LearningSimply

Figure 17.17 Aminoacyl-tRNA synthetases provide specificity in joining amino acids to their tRNAs. Linkage of a tRNA to its amino acid is an endergonic process that occurs at the expense of ATP, which loses two phosphate groups, becoming AMP.



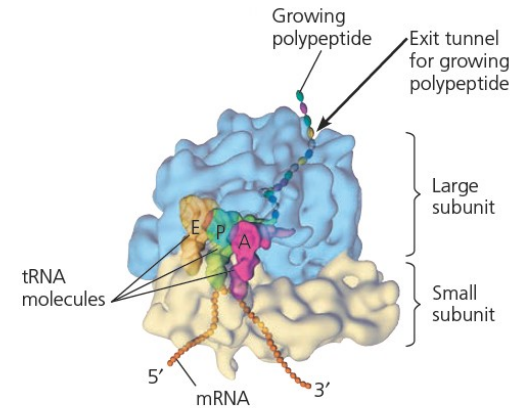
Overview

Molecular Components of Translation

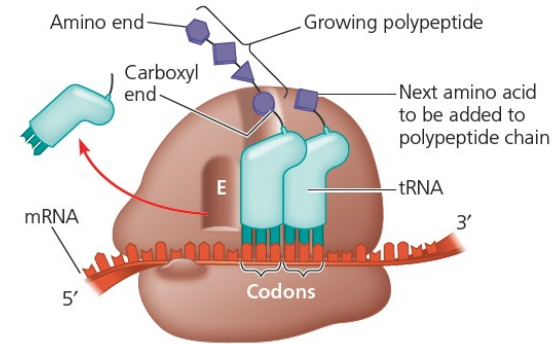
→ Ribosomes - the site where protein synthesis occurs

- ◆ Comprised of proteins as well as **rRNAs**
- ◆ Two subunits (large and small) each made up of different proteins and rRNA molecules
- ◆ A binding site for mRNA and 3 binding sites for tRNA molecules
- ◆ More than one ribosome can work on

https://www.youtube.com/watch?v=oQEXPxPdAwU&ab_channel=PAKTECHPOINT



(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 a complex of ribosomal RNA molecules and proteins.



(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 tRNAs leave from the E site. The polypeptide grows at its carboxyl end.

Overview

Molecular Components of Translation

→ 3 binding sites

- ◆ *E site* (exit site)

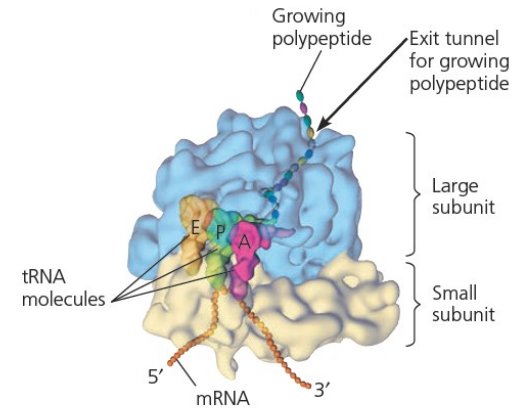
- Contains the uncharged tRNA (no longer has an amino acid attached to it)

- ◆ *P site* (peptide site)

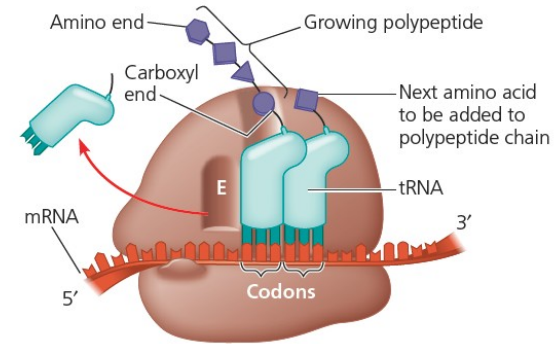
- Contains the tRNA with the growing polypeptide

- ◆ *A site* (amino site)

- Contains the tRNA with the next amino acid in the sequence



(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 a complex of ribosomal RNA molecules and proteins.



(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 tRNAs leave from the E site. The polypeptide grows at its carboxyl end.

The Molecular Events of Translation

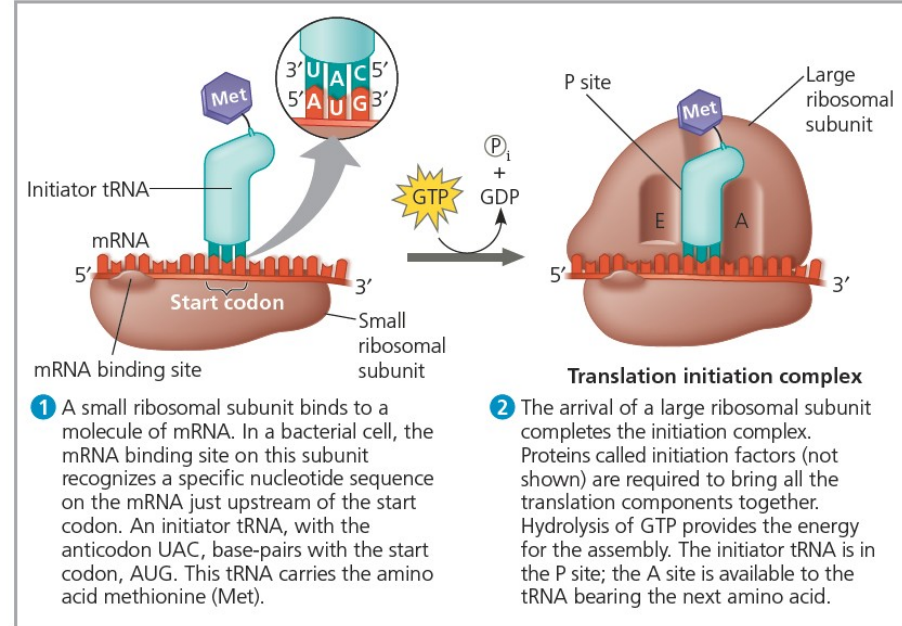
Initiation

- The small subunit attaches near the start codon (AUG) on the mRNA
- The initiator tRNA binds to the start codon (AUG)
- The large subunit joins the complex
- The start codon sets the **reading frame**; from there the codons are read 3 at a time

▼ Figure 17.19 The initiation of translation.



Animation: Initiation of Translation



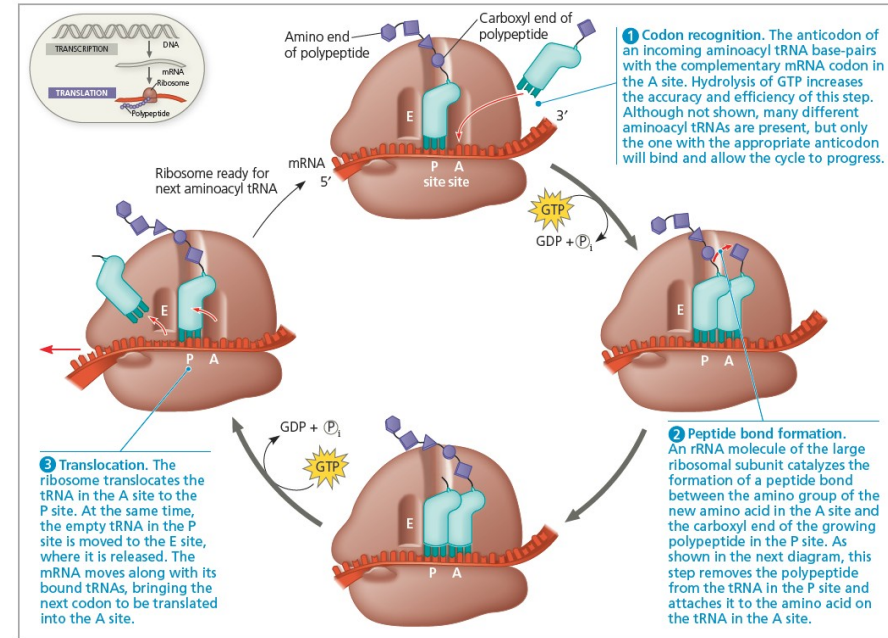
The Molecular Events of Translation

Elongation

- After the initiator tRNA (with methionine) bonds to the *P site*, the next tRNA (with the next amino acid) binds to the *A site*
- A **peptide bond** forms between the *P site* amino acid and the *A site* amino acid and the polypeptide transfers to the *A site* tRNA

▼ **Figure 17.20 The elongation cycle of translation.** The hydrolysis of GTP plays an important role in the elongation process; elongation factors are not shown.

Animation: Elongation Cycle of Translation



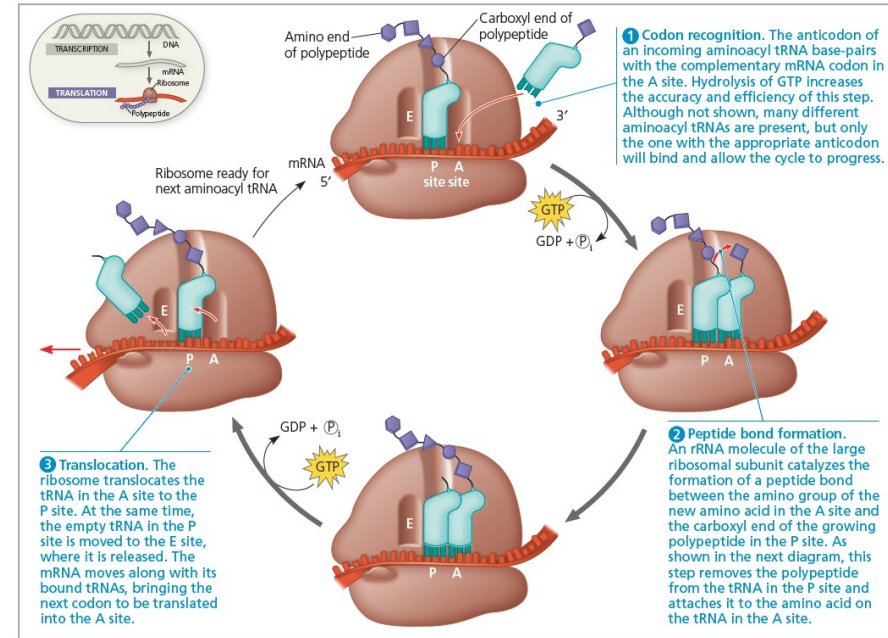
The Molecular Events of Translation

Elongation

- The tRNAs shift from:
 - ◆ *A site* → *P site* → *E site* → ejected
- The mRNA moves along with the tRNA with the polypeptide, exposing the next mRNA codon at the *A site*
- A new tRNA with a complementary anticodon binds to the *A site* with the next amino acid to be added to

▼ **Figure 17.20 The elongation cycle of translation.** The hydrolysis of GTP plays an important role in the elongation process; elongation factors are not shown.

Animation: Elongation Cycle of Translation



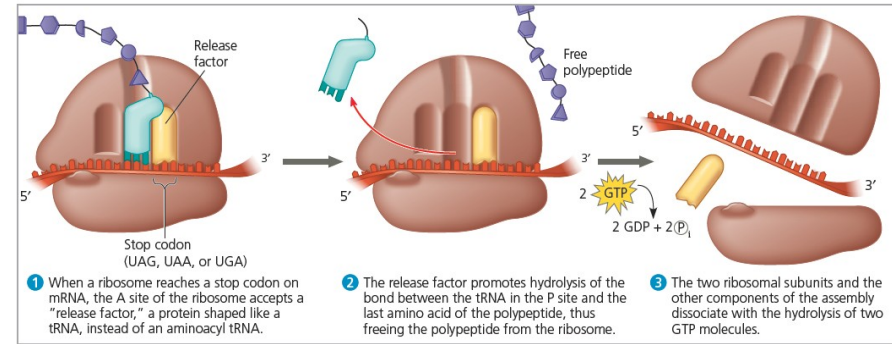
The Molecular Events of Translation

Termination

- A stop codon (UAA, UAG, UGA) on the mRNA aligns at the *A site*
- A release factor binds to the stop codon and cleaves the polypeptide off of the last tRNA at the *P site*
- The polypeptide is released and goes through further processing forming secondary, tertiary and quaternary

Figure 17.21 The termination of translation. Like elongation, termination requires GTP hydrolysis as well as additional protein factors, which are not shown here.

 Animation: Termination of Translation



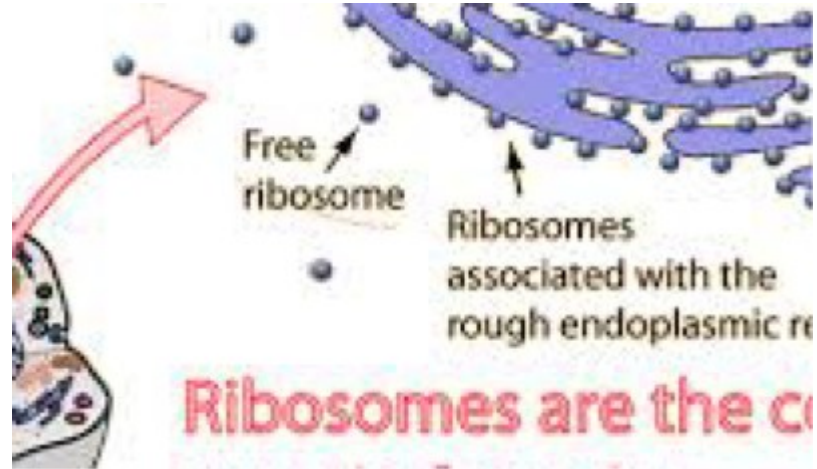
<https://www.youtube.com/watch?v=5bLEDd-PSTQ&channel=ndsuvirtualcell>

Free vs Bound Ribosome

- **Free ribosome**
- In cytoplasm
- Produce proteins that are used by the cell

Bound ribosome

- On the cytosolic side of the rough ER
- Transmembrane proteins (proteins that may be secreted into the ER or into the ER membrane)



Questions 13-18

https://www.youtube.com/watch?v=h3b9ArupXZg&t=3s&ab_channel=BozemanScience

Learning Check

Learning Check

- 13.** List and explain the major components of the translation machinery.
- 14.** Describe the structure and function of a polyribosome.
- 15.** Explain why translation is an energy-consuming process. Which organelle provides energy for this process?
- 16.** How is translation initiated and terminated?
- 17.** Use labelled diagrams to illustrate the events of the elongation phase of translation.
- 18.** Streptomycin is an antibiotic that works by inhibiting the attachment of tRNA that carries a modified form of methionine. Explain what effect this antibiotic must have on bacteria.

13. Answers may be based on **Table 6.4** on page 257 of the student textbook and should include mRNA, tRNA, ribosomes, and translation factors. The following information may be included:

- mRNA: contains the genetic information which determines a protein's amino acid sequence
- tRNA: a molecule that links mRNA codons with their corresponding amino acid
- ribosomes: a structure composed of rRNA and proteins which provides the site for protein synthesis
- translation factors: accessory proteins which are necessary for each stage of translation

14. A polyribosome is a complex composed of multiple ribosomes along a strand of mRNA. It can produce many copies of a protein at the same time.

15. Translation consumes large amounts of energy since many molecules (i.e., proteins and nuclei acid components) must be synthesized and assembled. Energy is also needed to form peptide bonds that exist between the amino acids in proteins. This energy is provided by mitochondria, which supply the cell with most of its energy.

Table 6.4 Major Components of the Translation Machinery

Component	Function
mRNA	contains genetic information that determines the amino acid sequence of a protein
tRNA	contains an anticodon that base-pairs with a codon on the mRNA and has the corresponding amino acid attached to it, according to the genetic code
Ribosomes	composed of rRNA and proteins; involved in the process of protein synthesis
Translation factors	proteins that act as accessory factors; needed at each stage of translation

16. Translation is initiated when initiation factors assemble the translation components. The small ribosomal subunit attaches to the mRNA near the start codon (AUG). The initiator tRNA (with anticodon UAC) binds to the start codon. The large ribosomal subunit then joins to form the complete ribosome. Translation is terminated when a stop codon on the mRNA is reached. This causes the polypeptide and the translation machinery to separate. The polypeptide is then cleaved from the last tRNA by a release factor.

17. Answers could be based on **Figure 6.14** on page 259 of the student textbook.

18. The antibiotic would prevent the initiation of translation of bacterial proteins. Therefore, the bacterial cells would not survive.

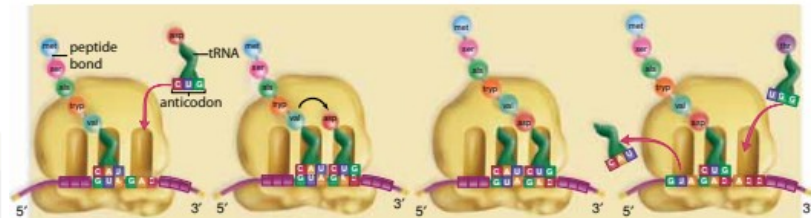


Figure 6.14 During elongation, one amino acid is added at a time onto the growing polypeptide chain.

1. A tRNA with an attached polypeptide is in the P site. A tRNA carrying the next amino acid enters the A site.

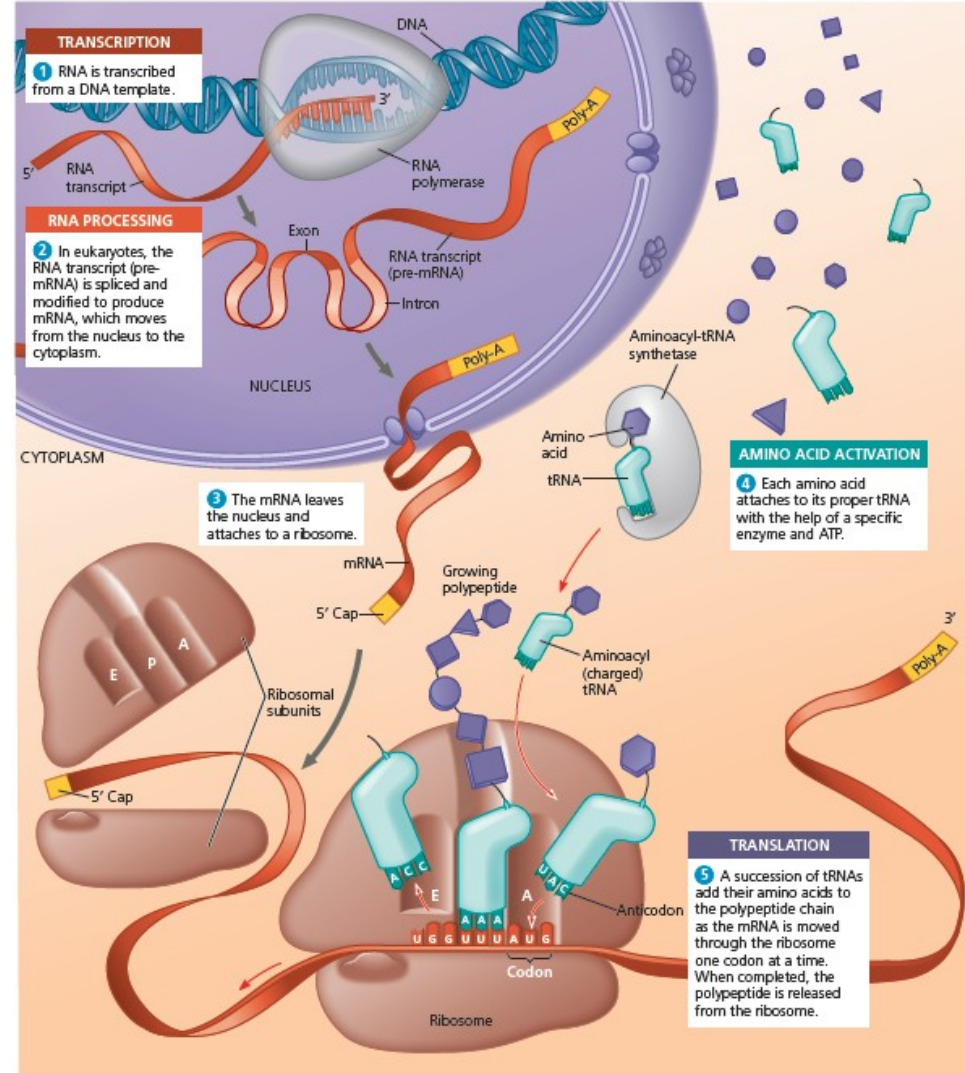
2. The polypeptide chain is transferred to the amino acid of the tRNA in the A site.

3. The polypeptide chain is now one amino acid longer.

4. The mRNA moves forward by one codon and the polypeptide-bearing tRNA is now at the P site. The tRNA that is no longer carrying an amino acid exits from the E site. The new codon is at the A site and is ready to receive the next complementary tRNA carrying the next amino acid of the polypeptide.

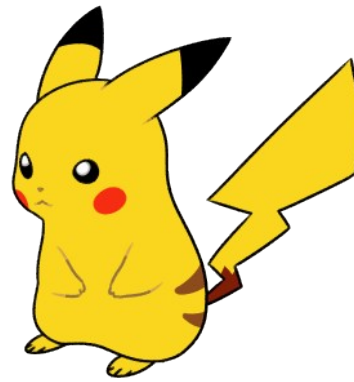
A Review of Gene Expression

- DNA template strand leads to...
- Precursor mRNA strand which is processed with...
 - ◆ 5' cap, 3' poly-A tail, intron removal resulting in...
- Mature mRNA which is recognized by the ribosome and translated between the start/stop codons using



Mutations

- Mutations, mistakes happens during DNA replication occasionally
- There can be four types of mutations:
 - Positive mutation (useful to survival/reproduction)
 - Negative mutation (harmful to survival/reproduction)
 - Neutral mutation (no effect)



no mutation
this pikachu is
in it's natural form



no mutation
although this pikachu has long fur
and a different eyecolor it is still
not a mutation, due to artists choice



bad mutation
this pikachu ate most likely
a bad pokepuff, mutations
like this are easy to spot due
to them being funny or illogical



true mutation
this pikachu is a true mutation
that is aesthetically pleasing
these often come with
nice recolors

DNA Mutations and Effects of Mutagens

Mutation

- A permanent change in the nucleotide sequence of a cell's DNA
- Are generally neutral or harmful but can be beneficial in rare cases - benefits can lead to the evolution of species
- **Single gene vs chromosomal mutations**

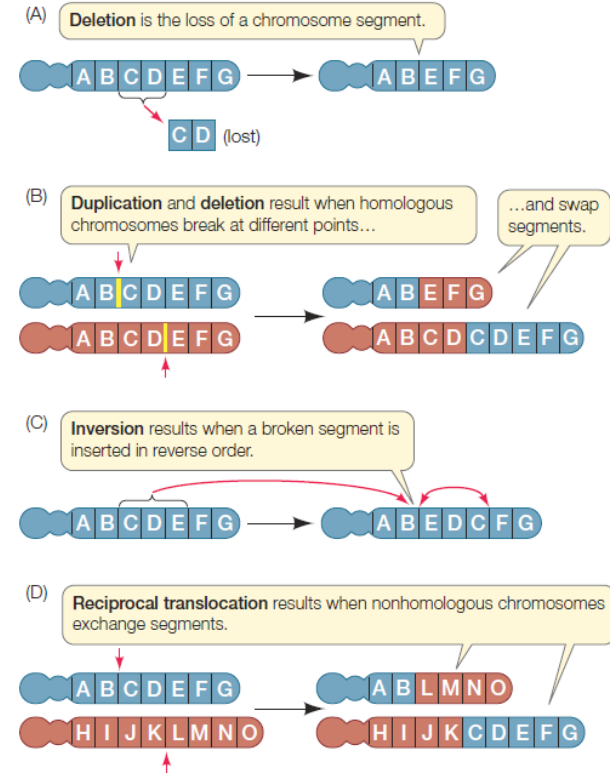


FIGURE 9.17 Chromosomal Mutations Chromosomes may break during replication, and parts of chromosomes may then rejoin incorrectly. The letters on these illustrations represent large chromosomal segments containing anywhere from zero to hundreds or thousands of genes.

DNA Mutations and Effects of Mutagens

Single-Gene Mutations

→ Point mutations

- ◆ A mutation involving a single base pair substitution, insertion or deletion

- ◆ Insertion or deletion can lead to a **frameshift mutation**

- ◆ Can results in: **silent**, **missense** or **nonsense** mutations

ORIGINAL SEQUENCE

• UGUAC AUG UAU ACG UCU CAA UGA UCCA
Met Tyr Ser Thr Gln STOP

POINT MUTATIONS

• UGUAC AUG UAU ACG UCU CAG UGA UCCA
Met Tyr Ser Thr Gln STOP

• UGUAC AUG UAU ACG CCU CAA UGA UCCA
Met Tyr Ser Pro Gln STOP

• UGUAC AUG UAA ACG UCU CAA UGA UCCA
Met STOP

Silent mutation that does not result in a change in the amino acid coded for and, therefore, does not cause any phenotypic change.

Missense mutation: a mutation that results in the single substitution of one amino acid in the resulting polypeptide

Nonsense mutation: a mutation that converts a codon for an amino acid into a termination codon

https://www.youtube.com/watch?v=JiWWsJRpA2M&ab_channel=CatalystUniversity

Frameshift mutations

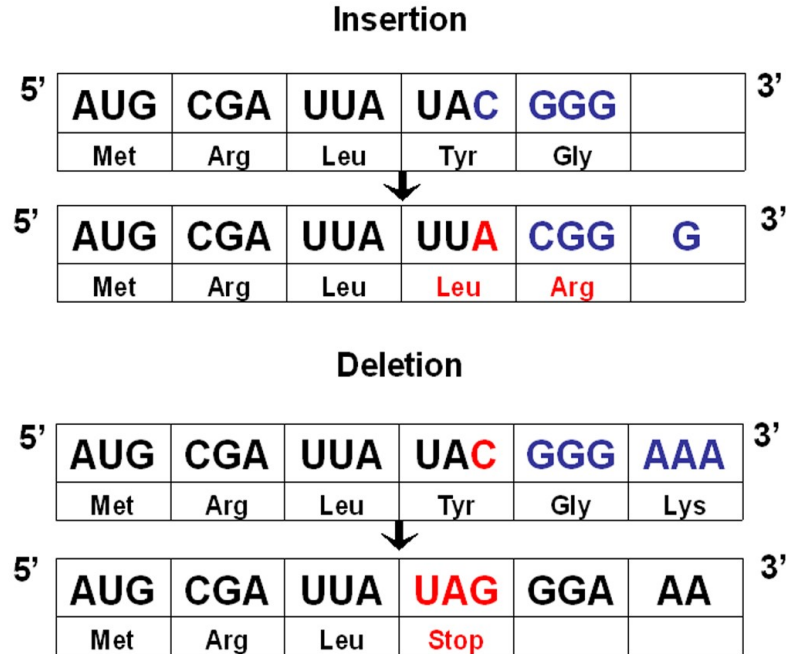


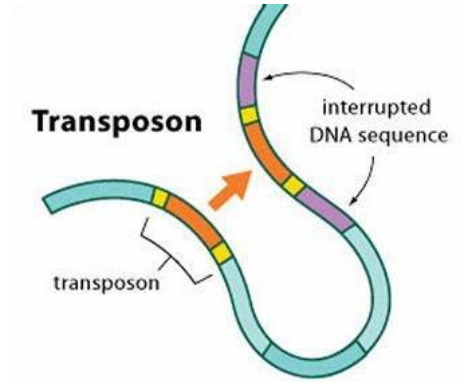
Figure 2. Schematic representation of nucleotide insertion and deletion

DNA Mutations and Effects of Mutagens

Chromosomal Mutations

https://www.youtube.com/watch?v=vl6Vlf2thvI&ab_channel=AmoebaSisters

- Deletion
- Duplication
- Inversions
- Translocations



DNA Transposons

- A short segment of DNA capable of moving within the genome of an organism; also called a jumping gene. If a transposon inserts itself into a functional gene, it will probably damage it. Insertion into **exons**, **introns**, and even into DNA flanking the genes (which may contain promoters and enhancers) can destroy or alter the gene's activity.

https://www.youtube.com/watch?v=eSD_tbjfSIA&ab_channel=NicoleLantz

DNA Mutations and Effects of Mutagens

Physical Mutagens

→ X-rays

- ◆ High-energy radiation that can have relatively minor effects including point mutations and can have large effects such as the loss of large portions of chromosomes
- ◆ UV radiation has a similar effect

Chemical Mutagens

https://www.youtube.com/watch?v=sX6LncNjTFU&t=101s&ab_channel=ProfessorDaveExplains

- A molecule that interacts with DNA in the nucleus
- Can cause a substitution or a frameshift mutation
 - ◆ Nitrites, gasoline fumes, cigarette smoke

DNA repair

Photorepair (specific)

- UV radiation can cause adjacent thymine to become linked together forming a dimer
- Photolyase repairs this specific through the use of visible light

Excision repair (non-specific)

- Removal of a damaged region of DNA and replacing it with the correct sequence



Learning Check

Learning Check

- 19.** How is it possible that some, but not all, mutations get passed from one generation to the next?
- 20.** Would a frameshift mutation occur if six nucleotides were deleted in a sequence of DNA? Explain your answer.
- 21.** Which type of mutation would be least harmful to an organism: silent, missense, or nonsense? Explain your answer.
- 22.** What is the difference between gene mutations and chromosomal mutations?
- 23.** What are two cellular processes that can cause mutations?
- 24.** Use an example to explain the difference between a specific and a non-specific DNA repair mechanism.

19. Mutations that occur in reproductive cells can be passed onto future generations. Mutations which occur in somatic cells do not get passed on from one generation to another.
20. No, since the deletion of nucleotides is divisible by three.
21. A silent mutation has no effect on the amino acids of a protein, and therefore would be the least harmful to an organism. Missense mutations cause alterations in the amino acids of a protein, and nonsense mutations results in a shortened protein due to a premature stop codon.
22. Single-gene mutations involve changes to the nucleotide sequence of one gene. Chromosomal mutations involve changes in chromosomes, and therefore may affect many genes.

23. Spontaneous mutations may arise during DNA replication if there is incorrect base pairing by DNA polymerase. DNA transposition can also cause mutations by the movement of specific DNA sequences (transposons, or "jumping genes") moving within and between chromosomes.
24. UV radiation can lead to a mutation by covalently linking thymines to form a thymine dimer. A specific mechanism for repairing thymine dimers is photorepair, where an enzyme specifically recognizes and cleaves thymine dimers. A non-specific mechanism for repairing UV damage is excision repair, where a group of enzyme repair enzymes identify and correct many different types of DNA damage.

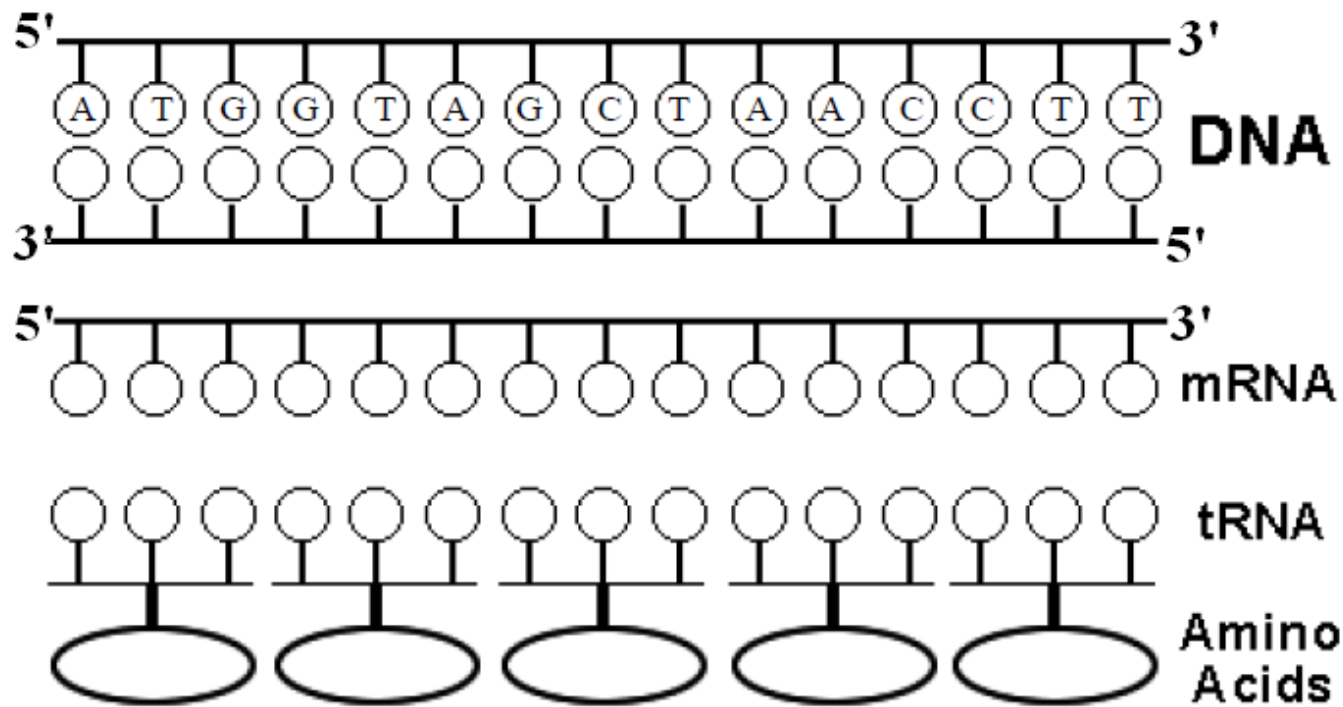
Remember me?

The Genetic Code

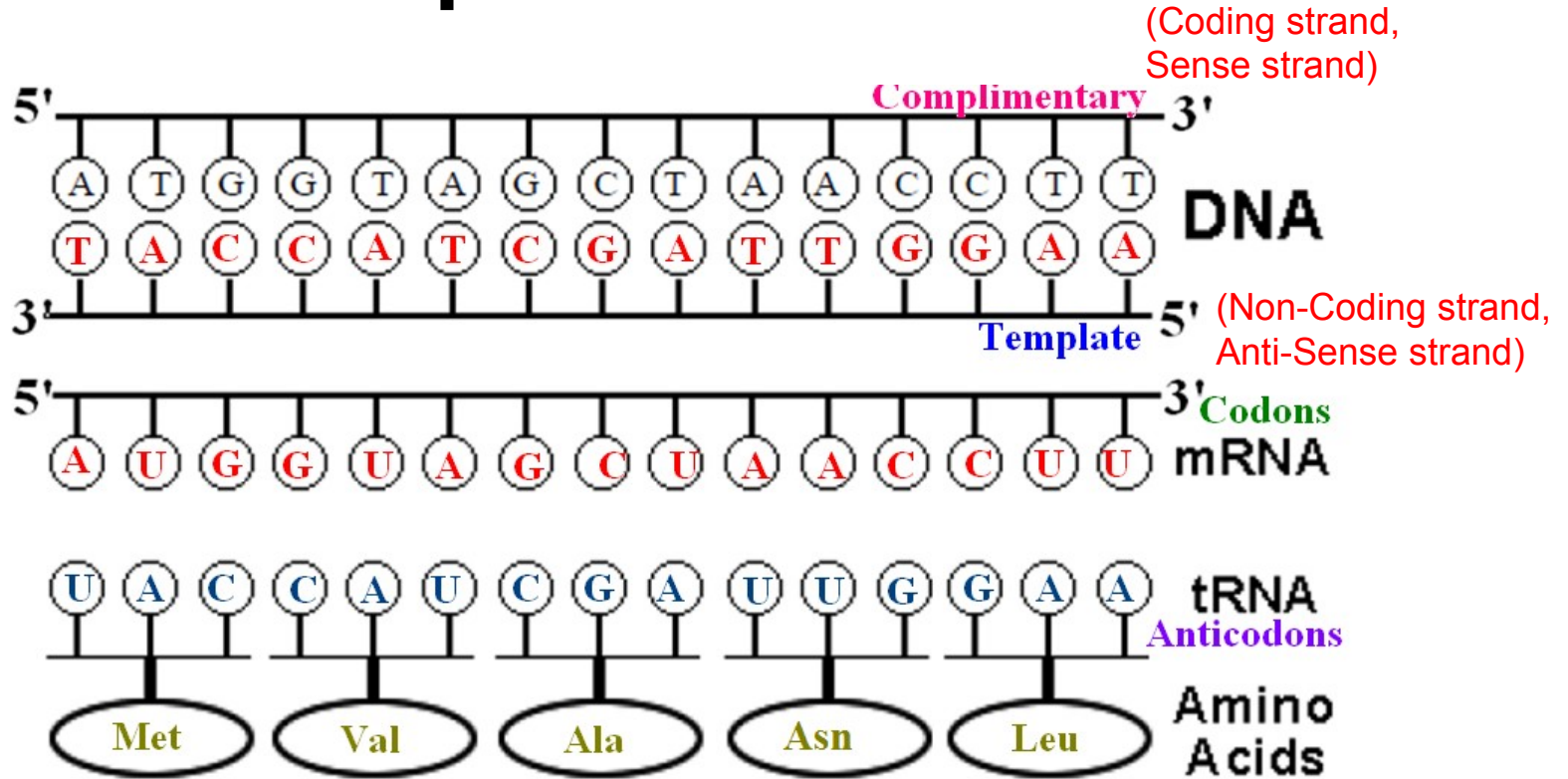
	U	C	A	G
U	UUU Phenylalanine UUC alanine UUG Leucine UUA Leucine	UCU Serine UCC Serine UCA Serine UCG Serine	UAU Tyrosine UAC Tyrosine UAA Stop UAG Stop	UGU Cysteine UGC Cysteine UGA Stop UGG Tryptophan
C	CUU Leucine CUC Leucine CUA Leucine CUG Leucine	CCU Proline CCC Proline CCA Proline CCG Proline	CAU Histidine CAC Histidine CAA Glutamine CAG Glutamine	CGU Arginine CGC Arginine CGA Arginine CGG Arginine
A	AUU Isoleucine AUC Isoleucine AUA Isoleucine AUG Methionine	ACU Threonine ACC Threonine ACA Threonine ACG Threonine	AAU Asparagine AAC Asparagine AAA Lysine AAG Lysine	AGU Serine AGC Serine AGA Arginine AGG Arginine
G	GUU Valine GUC Valine GUA Valine GUG Valine	GCU Alanine GCC Alanine GCA Alanine GCG Alanine	GAU Aspartic acid GAC Aspartic acid GAA Glutamic acid GAG Glutamic acid	GGU Glycine GGC Glycine GGA Glycine GGG Glycine

- Eukaryotic cell
ALWAYS
BEGINS
SEQUENCE BY
THE AMINO
ACID
METHIONINE
- UAA, UGA and
UAG in amino
acid sequence
means STOP

Transcription to Translation

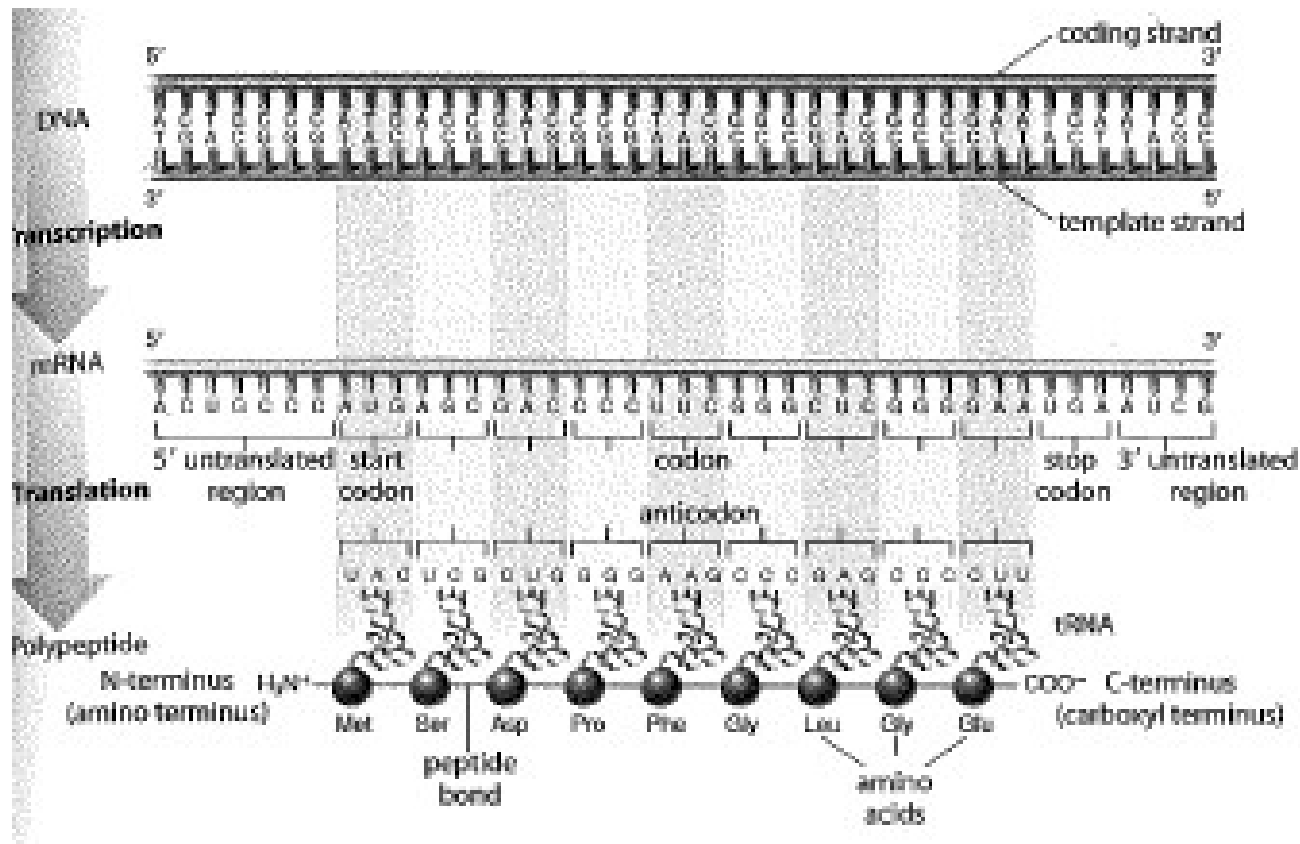


Transcription to Translation



And don't forget our good UGLY friends in the stop codons!!!
UAA UGA UAG

Recap



Questions 1, 2, 3, 5, 6, 7, 8, 9, 10, 11, **12, 13**

Topic Review Questions

- 1. K/U** List and describe the major components of the translation machinery.
- 2. C** Draw the general structure of a tRNA molecule. Label each component. Write a short caption explaining the function of tRNA.
- 3. T/I** Copy the table below into your notebook. The nucleotide sequence in a fragment of an antisense strand of DNA is 3'-CGGAAATTG-5'. Based on this sequence, complete the table.

Codon (mRNA)	Anticodon (tRNA)	Amino Acid

- 5. K/U** Why does translation require a large amount of energy from the cell?
- 6. C** Use labelled diagrams to illustrate the four-step cycle in the elongation phase of translation.
- 7. T/I** A mutation has occurred in the DNA of an individual's skin cells. Will this mutation be passed onto future offspring?
- 8. K/U** Distinguish between gene mutations and chromosomal mutations.
- 9. T/I** In what sections of the genome would transposons cause the most damage? Explain your answer.
- 10. K/U** List and describe two types of mutagens. Provide an example for each type.
- 11. K/U** List and describe two types of DNA repair. Provide an example for each.

- 12. T/I** Use the coding sequence below to answer the following questions.

mRNA codons: UUA-CCU-GUU-AUU

Amino acids: leu-pro-val-thr

- Add a single guanine nucleotide to the beginning of the codon sequence. What type of mutation would this insertion produce?
- Write the corresponding amino acids that would result from the addition of the single guanine nucleotide.

- 13. T/I** Use the DNA sequence template below to answer the following questions.

3'-TACTTACTCGTCAACCTT-5'

- Write the corresponding mRNA coding sequence and amino acid sequence for the DNA template strand.
- A nucleotide substitution occurs in the DNA template at position 14, where adenine is replaced by thymine. Write the mRNA coding sequence and amino acid sequence that would result from this substitution.
- What type of mutation would result from this nucleotide substitution?



References

Carter-Edwards, T., Gerards, S., Gibbons, K., McCallum, S., Noble, R., Parrington, J., Ramlochan, C., Ramlochan, S. (2011). *Biology 12*. McGraw-Hill Ryerson Limited

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