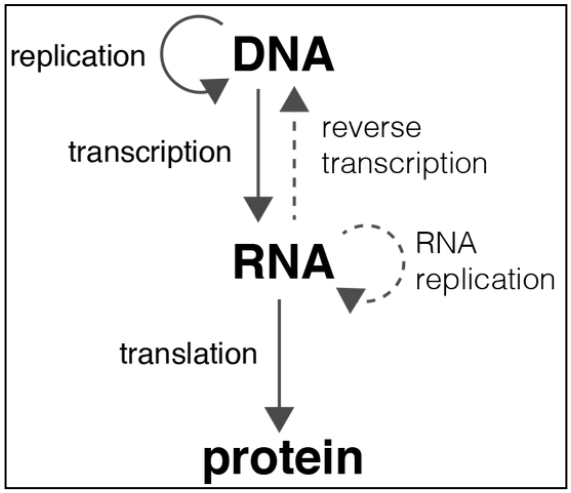
AP Biology **Interactive Student Study Guide**

North Salem University

MISSION: *Engage students to continuously learn, question, define and solve problems through critical and creative thinking.*

Fall 2023

*This chapter is going to be a very long journey, but it is crucial to your understanding of the **Central Dogma of Biology** which provides the basic framework for how genetic information flows from a DNA sequence to an amino acid sequence (protein product) inside cells. This process of genetic information flowing from DNA to RNA to protein is called gene expression.*



If you have any problems – please sign up for extra help after school.

Chapter 17:
From Gene to Protein

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OBJECTIVES:

The Connection between Genes and Proteins

__1. Explain the reasoning that led Archibald Garrod to first suggest that genes dictate phenotypes through enzymes.
__2. Explain Beadle and Tatum's contribution to our understanding of how genes control metabolism.
__3. Distinguish between the "one gene-one enzyme" hypothesis and the "one gene-one polypeptide" hypothesis and explain why the original hypothesis was changed.
__4. Explain how RNA differs from DNA.
__5. Briefly explain how information flows from gene to protein.
__6. Distinguish between transcription and translation.
__7. Compare where transcription and translation occur in prokaryotes and in eukaryotes.
__8. Define "codon" and explain the relationship between the linear sequence of codons on mRNA and the linear sequence of amino acids in a polypeptide.
__9. Explain the early techniques used to identify what amino acids are specified by the triplets UUU, AAA, GGG, and CCC.
__10. Explain why polypeptides begin with methionine when they are synthesized.
__11. Explain in what way the genetic code is redundant and unambiguous.
__12. Explain the significance of the reading frame during translation.
__13. Explain the evolutionary significance of a nearly universal genetic code.

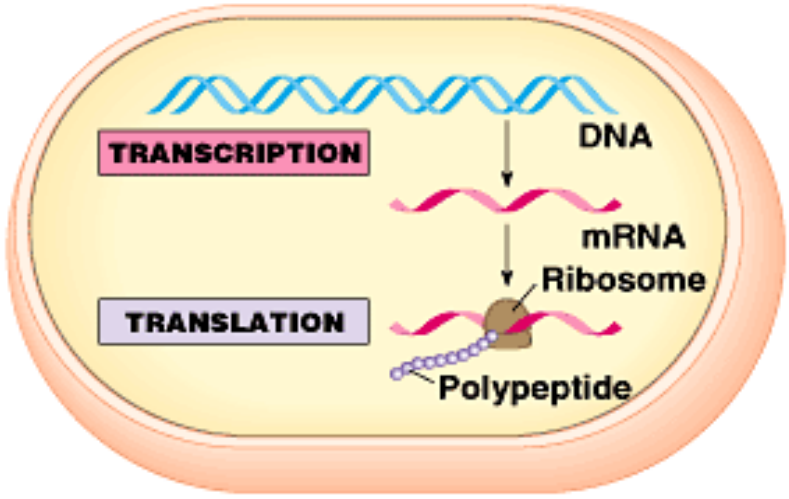
The Synthesis and Processing of RNA

__14. Explain how RNA polymerase recognizes where transcription should begin.
__15. Describe the promoter, the terminator, and the transcription unit.
__16. Explain the general process of transcription, including the three major steps of initiation, elongation, and termination.
__17. Explain how RNA is modified after transcription in eukaryotic cells.
__18. Define and explain the role of ribozymes.
__19. Describe the functional and evolutionary significance of introns.

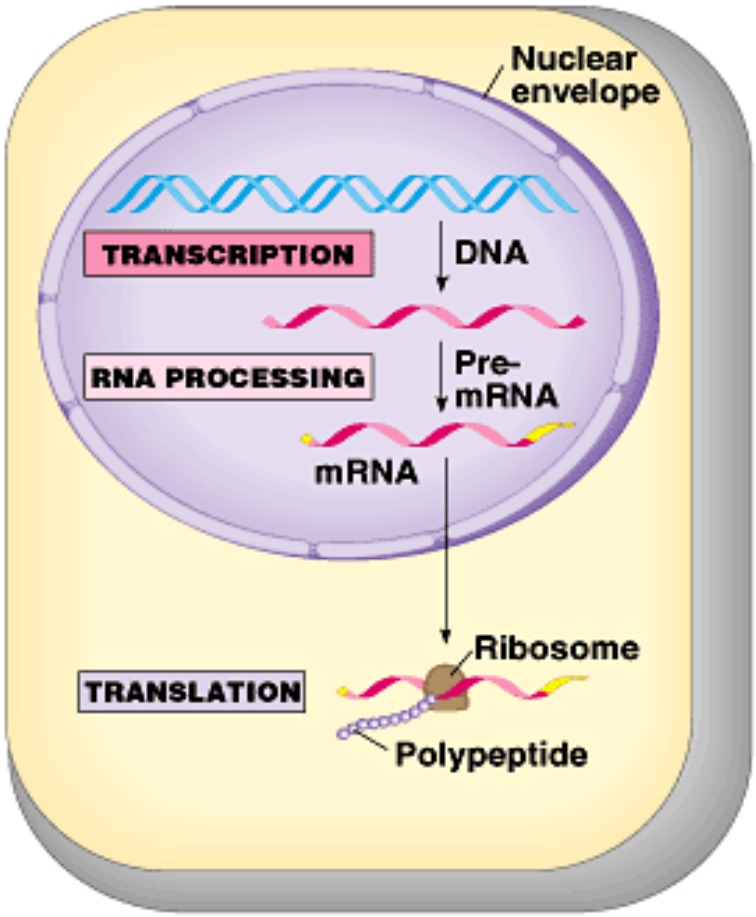
The Synthesis of Protein

__20. Describe the structure and functions of tRNA.
__21. Describe the structure and functions of ribosomes.
__22. Describe the process of translation (including initiation, elongation, and termination).
__23. Explain what determines the primary structure of a protein and describe how a polypeptide must be modified before it becomes fully functional.
__24. Describe two properties of RNA that allow it to perform so many different functions.
__25. Compare protein synthesis in prokaryotes and eukaryotes.
__26. Define "point mutations." Distinguish between base-pair substitutions and base-pair insertions. Give examples of each and note the significance of such changes.
__27. Describe several examples of mutagens and explain how they cause mutations.

The Central Dogma of Biology

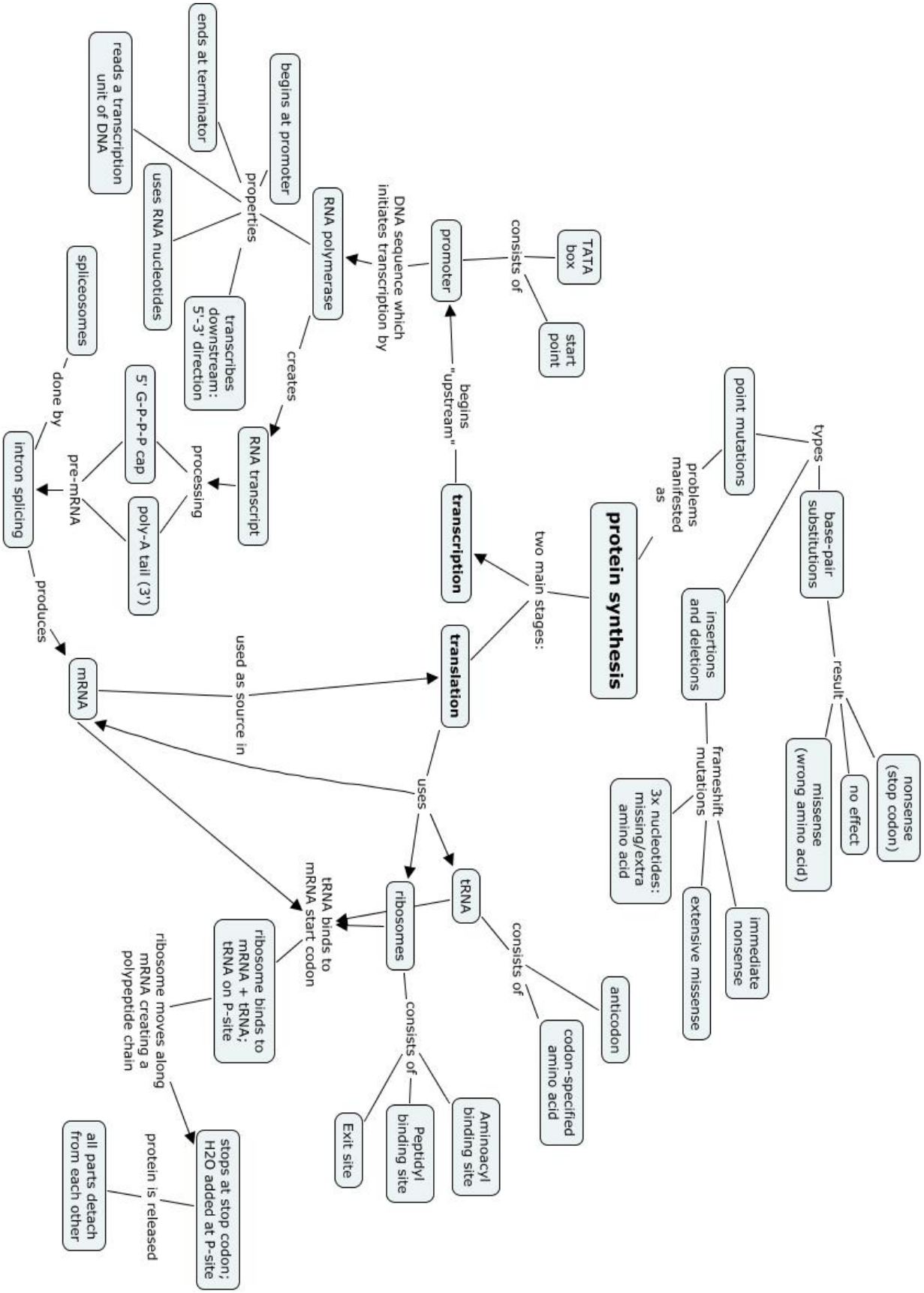


(a) Prokaryotic cell



(b) Eukaryotic cell

Chapter 17: Concept Map



THE CONNECTION BETWEEN GENES AND PROTEINS

1. What is a gene?

2. What is *gene expression*?

3. What situation did Archibald Garrod suggest caused inborn errors of metabolism?

4. Describe one example Garrod used to illustrate his hypothesis.

5. State the hypothesis formulated by George Beadle while studying eye color mutations in *Drosophila*.

6. What revision of detail (*but not of basic principle*) did this hypothesis undergo as more information was gained? Write this restatement and then box or highlight it. This is an important concept and is related to your answer to the previous question!

7. Explain the statement, "All enzymes are proteins but not all proteins are enzymes."

Basic Principles of Transcription and Translation

This section will introduce you to the processes and associated terminology in the form of an overview. Once you have the big picture, you will take a closer look in the next few concepts.

8. From the first paragraph in this section, find three ways in which RNA differs from DNA.

(1)

(2)

(3)

9. What are the monomers of DNA and RNA called?

10. What are the monomers of proteins called?

11. Define each of these processes that are essential to the formation of a protein:

(1) <u>transcription</u> -

(2) <u>translation</u> –

12. Complete the following table to summarize each process:

	Template	**Product Synthesized**	**Location in Eukaryotic Cells**
Transcription			
Translation			

13. In eukaryotes, what is the pre-mRNA called?

14. How many DNA nucleotide bases are there? _____ How many amino acids are there? _____

15. How many nucleotides are required to code for these 20 amino acids? _____

16. So, the language of DNA is a triplet code. How many unique triplets exist? _____
4 x 4 x 4 or 4^3

17. DNA is double-stranded, but for each protein, only one of these two strands is used to produce an mRNA transcript. What is the coding strand called?

18. Here is a short DNA template. Below it, assemble the complementary mRNA strand.

3' A C G A C C A G T A A A 5'

***m*RNA** = _____

19. How many codons are there above? _____ Put a box around one codon.

20. What was the first codon–amino acid pair to be identified? _____

21. Of the 64 possible codons, how many code for amino acids? _____

22. What event is coded for by UAA, UAG and UGA? _____

23. What is the start codon? _____

24. Use the table to the left to help you explain why is the genetic code said to be *redundant* but not *ambiguous*?

The Genetic Code

First base (5′ end)	Second base: U	Second base: C	Second base: A	Second base: G	Third 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

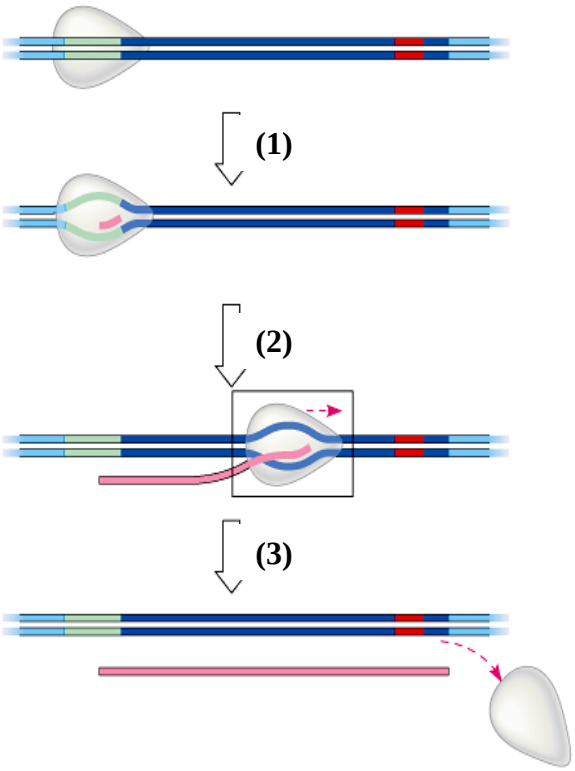
25. Explain the concept of a reading frame.

26. Now here is an important idea: **DNA is DNA is DNA**. By this we mean that the code is nearly ***universal***, and because of this, jellyfish genes can be inserted into pigs, or firefly genes can make a tobacco plant glow. Enjoy a look at Figure 17.5 in your text . . . and no question to answer here!

27. Name the enzyme that uses the DNA template strand to transcribe a new mRNA strand.

28. You will recall from Chapter 16 that DNA polymerase adds new nucleotides to the template DNA strand to assemble each new strand of DNA. Both enzymes can assemble a new polynucleotide only in the 5' → 3' direction. What does this mean exactly?

29. Figure 17.6 in your text will require a bit of study. Use it to label the following elements on the diagram below: promoter, RNA polymerase, transcription unit, terminator, template of DNA, and RNA transcript. Then, to the right of the figure, name the three stages of transcription and briefly describe each stage. *(Activity 17B)*



(1) <u>Initiation</u> -

(2) <u>Elongation</u> -

(3) <u>Termination</u> -

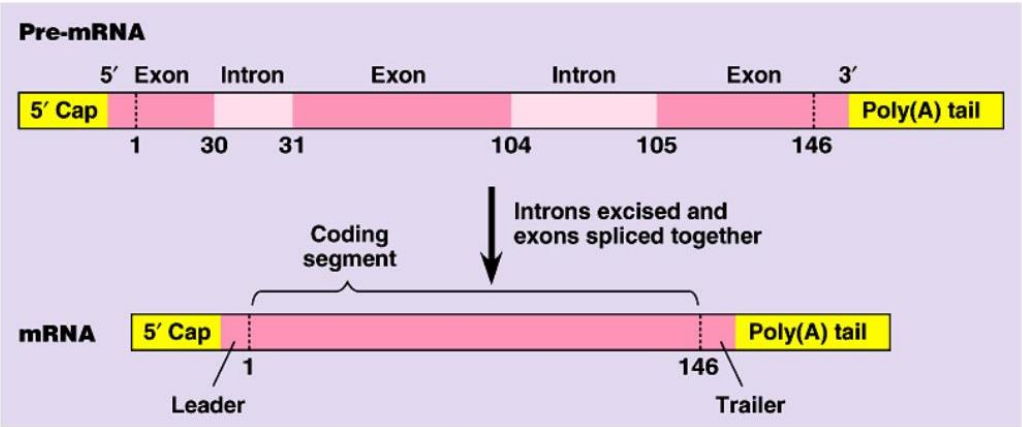
30. What is the difference between the promoter and terminator?

31. What is a transcription unit?

32. How is the biding of RNA polymerase to the promoter different in prokaryotes and eukaryotes?

33. What are transcription factors?

34. RNA processing occurs **only** in eukaryotic cells. The primary transcript is altered at both ends, and sections in the middle are removed. Use the diagram below to help you answer the next two questions.



(a) What happens at the 5' end?

(b) What happens at the 3' end?

(c) Distinguish between introns and exons. **HINT:** Exons are expressed.

35. What are two important functions of the 5' cap and poly-A tail?

(1)

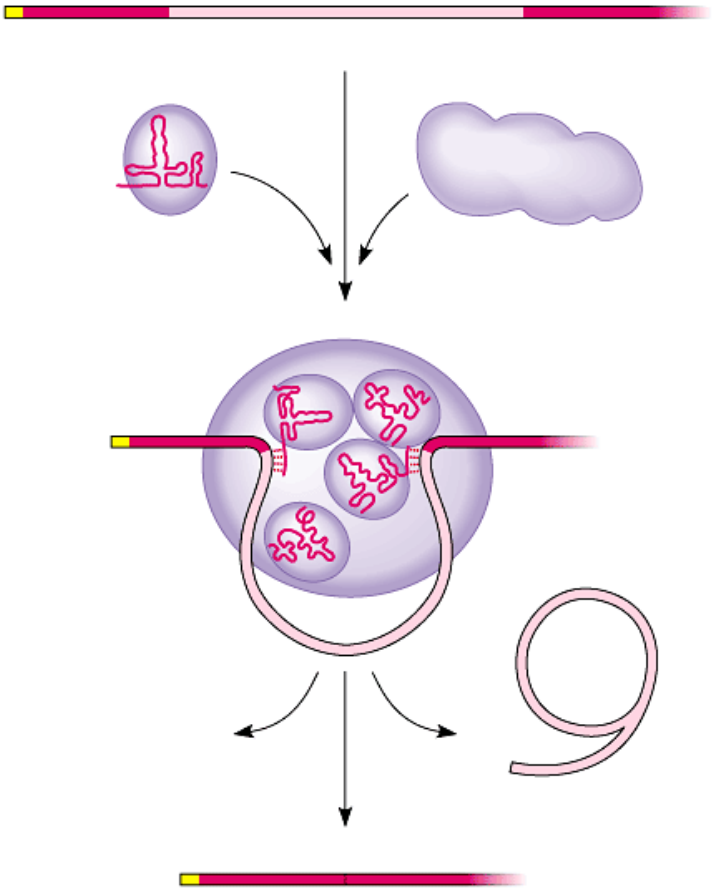
(2)

36. What are snRNPs? What two types of molecules make up a snurp?
(I like the word snurp! It reminds me of little blue cartoon characters called smurfs.)

37. You will be introduced to a number of small RNAs in this course. What type of RNA in a snRNP?

38. Snurps band together in little snurp groups to form spliceosomes. What do spliceosomes do?

39. On the figure below, label the following: pre-mRNA, snRNPs, snRNA, protein, spliceosomes, intron, excised intron, other proteins and mRNA.



40. What is a ribozyme?

41. What commonly held idea was rendered obsolete by the discovery of ribozymes?

42. What is the function of tRNA?

43. What is an anticodon?

44. Transfer RNA (tRNA) has two attachment sites. What binds at each site?

45. How many different aminoacyl-tRNA synthetases are there? _____

46. How does a prokaryotic ribosome differ from a eukaryotic ribosome? What is the medical significance of this difference?

47. On the diagram below, label the large subunit, small subunit, A, P, and E sites, mRNA binding site. To the right of the figure, explain the functions of the A, P, and E sites. *(Activity 17D)*

A site –

P site –

E site -

48. Much like transcription, we can divide translation into three stages. Briefly describe each stage.

(1) <u>Initiation</u> –

(2) <u>Elongation</u> –

(3) <u>Termination</u> –

49. What is always the first amino acid in the new polypeptide? _____

50. What are polyribosome and what advantage do they serve? [**Figure 17.20**]

51. Protein modification occurs in the ER. How are proteins targeted for the ER.

52. Define a mutation in terms of molecular genetics.

53. Define point mutations.

54. What are frameshift mutations?

55. Identify two mechanisms by which frameshifts may occur.

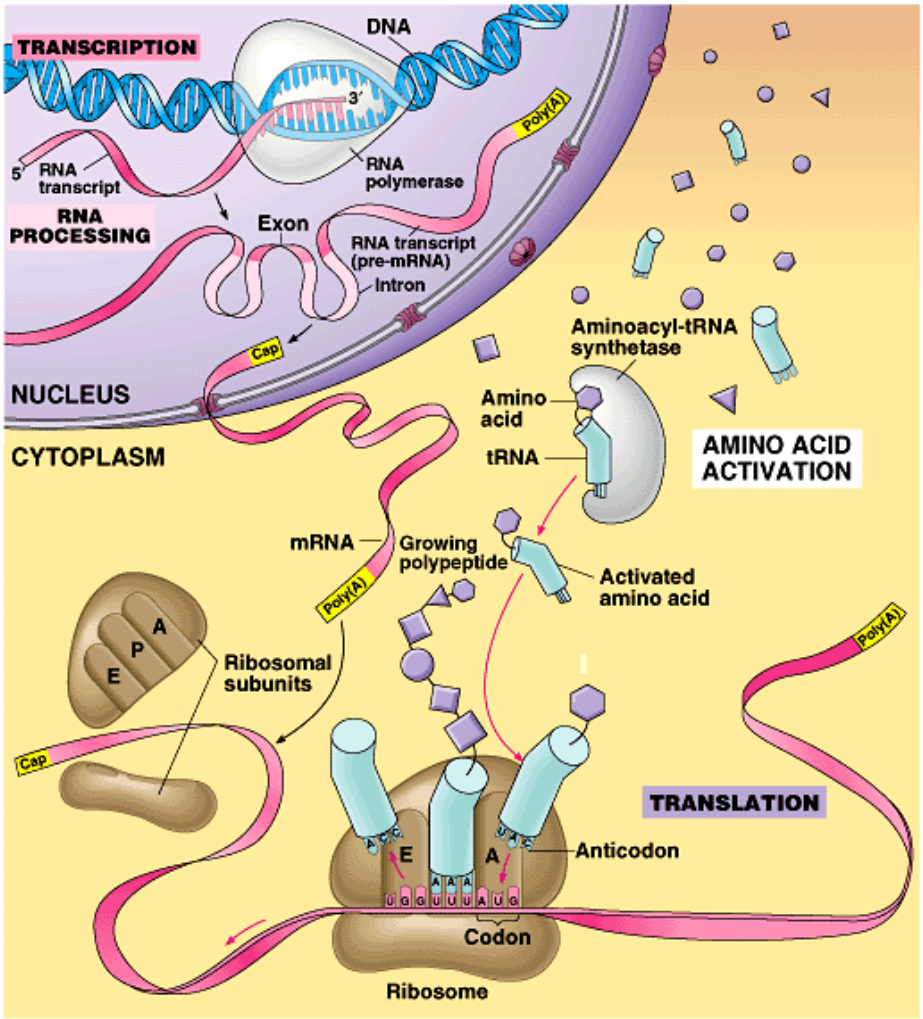
56. What is the difference between a nonsense and missense mutation?

57. How can a base-pair substitution result in a silent mutation?

58. What are mutagens?

59. What are carcinogens?

Finally, use this summary figure to put together all that you have learned in this chapter.



Chapter 17: Summary of Key Concepts

THE CONNECTION BETWEEN GENES AND PROTEINS

- The study of metabolic defects provided evidence that genes specify proteins (pp. 303-304, FIGURE 17.1) DNA controls metabolism by directing cells to make specific enzymes and other proteins. Beadle and Tatum's experiments with mutant strains of Neurospora supported the one gene-one enzyme hypothesis, later modified to one gene-one polypeptide. In most cases, a gene determines the amino acid sequence of a polypeptide chain.
- Transcription and translation are the two main processes linking gene to protein: an overview (pp. 304-306, FIGURE 17.2) Both nucleic acids and proteins are informational polymers with linear sequences of monomers--nucleotides and amino acids, respectively. Transcription is the nucleotide-to-nucleotide transfer of information from DNA to RNA, while translation is the informational transfer from nucleotide sequence in RNA to amino acid sequence in a polypeptide.
- In the genetic code, nucleotide triplets specify amino acids (pp. 306-308, FIGURES 17.3, 17.4) A codon is a nucleotide triplet that in mRNA is either translated into an amino acid (61 codons) or serves as a translational stop signal (3 codons). The codon for methionine, AUG, also acts as a translational start signal.
- The genetic code must have evolved very early in the history of life (pp. 308-309) The near universality of the genetic code suggests that it was present in ancestors common to all kingdoms of life.

THE SYNTHESIS AND PROCESSING OF RNA

- Transcription is the DNA-directed synthesis of RNA: a closer look (pp. 309-311, FIGURES 17.6, 17.7) RNA synthesis on a DNA template is catalyzed by RNA polymerase. It follows the same base-pairing rules as DNA replication, except that in RNA, uracil substitutes for thymine. Promoters, specific nucleotide sequences at the start of a gene, signal the initiation of RNA synthesis. Transcription factors (proteins) help eukaryotic RNA polymerase recognize promoter - sequences. Transcription continues until a particular RNA sequence signals termination.
- Eukaryotic cells modify RNA after transcription (pp. 311-313, FIGURES 17.8-17.10) Eukaryotic mRNA molecules are processed before leaving the nucleus by modification of their ends and by RNA splicing. The 5' end receives a modified nucleotide cap, and the 3' end a poly(A) tail. These seem to protect the molecule from degradation and enhance translation. Most eukaryotic genes have introns, noncoding regions interspersed among the coding regions, exons. In RNA splicing, introns are removed and exons joined. RNA splicing is catalyzed by small nuclear ribonucleoproteins (snRNPs), operating within larger assemblies called spliceosomes. In some cases, RNA alone catalyzes splicing. Catalytic RNA molecules are called ribozymes. The shuffling of exons by recombination may contribute to the evolution of protein diversity.

THE SYNTHESIS OF PROTEIN

- Translation is the RNA-directed synthesis of a polypeptide: a closer look (pp. 313-320, FIGURES 17.17-17.19) After picking up specific amino acids, transfer RNA (tRNA) molecules line up by means of their anticodon triplets at complementary codons on mRNA. The attachment of a specific amino acid to its particular tRNA is an ATP-driven process catalyzed by an aminoacyl-tRNA synthetase enzyme. Ribosomes coordinate the three stages of translation: initiation, elongation, and termination. Each ribosome is composed of two subunits made of protein and ribosomal RNA (rRNA). Ribosomes have a binding site for mRNA; P and A sites that hold adjacent tRNAs as amino acids are linked in the growing polypeptide chain; and an E site for release of tRNA. The formation of peptide bonds is catalyzed by one of the rRNA molecules. A number of ribosomes can work on a single mRNA molecule simultaneously, forming a polyribosome. After translation, the protein may be modified in ways that affect its three-dimensional shape.
- Signal peptides target some eukaryotic polypeptides to specific destinations in the cell (pp. 320-321, FIGURE 17.21) Free ribosomes in the cytosol initiate the synthesis of all proteins, but proteins destined for membranes or for export from the cell complete their synthesis only after the ribosomes making them attach to the endoplasmic reticulum. In the latter case, a signal-recognition particle (SRP) binds to a signal sequence on the leading end of the growing polypeptide, enabling the ribosome to bind to the ER. Other signal sequences target proteins for mitochondria or chloroplasts.
- RNA plays multiple roles in the cell: a review (p. 321, TABLE 17.1) More versatile than DNA, RNA performs structural, informational, and catalytic roles.
- Comparing protein synthesis in prokaryotes and eukaryotes: a review (pp. 321-322) In a bacterial cell, which lacks a nuclear envelope, translation of an mRNA can begin while transcription is still in progress. In a eukaryotic cell, the nuclear envelope separates transcription from translation; extensive RNA processing occurs in the nucleus.
- Point mutations can affect protein structure and function (pp. 322-325, FIGURE 17.24) Point mutations are changes in one base pair of DNA. Base-pair substitutions can cause missense or nonsense mutations, which are often detrimental to protein function. Base-pair insertions or deletions may produce frameshift mutations that disrupt the mRNA reading frame downstream of the mutation. Spontaneous mutations can occur during DNA replication or repair. Various chemical and physical mutagens can also alter genes.
- What is a gene? revisiting the question (p. 325, FIGURE 17.25) A gene is usually a region of DNA encoding a polypeptide, but some genes have RNA molecules as their final products.

Chapter 17 - Review Questions

__1) The monomers of DNA and RNA are -
A) monosaccharides.
B) nucleotides.
C) fatty acids.
D) nucleic acids.

__2) What is the flow of information for the synthesis of proteins according to the central dogma?
A) DNA to mRNA to protein
B) DNA to protein to mRNA to protein
C) DNA to mRNA to tRNA to protein
D) mRNA to DNA to mRNA to protein

__3) The DNA of virus A is inserted into the protein coat of virus B. The combination virus is used to infect E. coli. The virus particles produced by the infection are analyzed for DNA and protein contents. What results would you expect?
A) DNA and protein from B
B) DNA from A and protein from B
C) DNA and protein from A
D) DNA from B and protein from A

__4) The AUC and AUA codons in mRNA both specify isoleucine. What feature of the genetic code explains this?
A) complementarity
B) nonsense codons
C) degeneracy
D) universality

__5) How many nucleotides are in 12 mRNA codons?
A) 12 B) 24 C) 36 D) 48

__6) Which of the following statements regarding RNA is *false*?
A) RNA uses the sugar dextrose.
B) RNA uses the nitrogenous base uracil.
C) One RNA molecule can include four different nucleotides in its structure.
D) RNA molecules have a sugar-phosphate backbone.

__7) The term "gene expression" refers to the -
A) fact that each individual of a species has a unique set of genes.
B) fact that individuals of the same species have different phenotypes.
C) process by which genetic information flows from genes to proteins.
D) flow of information from parent to offspring.

__8) Which of the following options best depicts the flow of information when a gene directs the synthesis of a cellular component?
A) RNA → DNA → RNA → protein
B) DNA → RNA → protein
C) protein → RNA → DNA
D) DNA → tRNA → mRNA → protein

__9) The transfer of genetic information from DNA to RNA is called -
A) translation.
B) initiation.
C) transcription.
D) elongation.

__10) The "one gene-one polypeptide" theory states that -
A) the synthesis of each gene is catalyzed by one specific enzyme.
B) the synthesis of each enzyme is catalyzed by one specific gene.
C) the function of an individual gene is to dictate the production of a specific polypeptide.
D) the function of each polypeptide is to regulate the synthesis of each corresponding gene.

__11) Experiments have demonstrated that the "words" of the genetic code (*the units that specify amino acids*) are -
A) single nucleotides.
B) two-nucleotide sequences.
C) three-nucleotide sequences.
D) nucleotide sequences of various lengths.

__12) The directions for each amino acid in a polypeptide are indicated by a codon that consists of ____ nucleotide(s) in an RNA molecule.
A) 2 B) 3 C) 4 D) 5

__13) We would expect that a 15-nucleotide sequence ending with a stop codon will direct the production of a polypeptide that consists of -
A) 2 amino acids.
B) 3 amino acids.
C) 4 amino acids.
D) 5 amino acids.

__14) In the genetic code, -
A) some codons specify more than one amino acid.
B) some codons consist of two nucleotides.
C) some amino acids are not specified by any codons.
D) many amino acids are specified by more than one codon.

__15) Which of the following enzymes catalyzes the linking together of RNA nucleotides to form RNA?
A) RNA polymerase
B) RNA ligase
C) a ribozyme
D) tRNA

__16) Which of the following occurs when RNA polymerase attaches to the promoter DNA?
A) elongation of the growing RNA molecule
B) termination of the RNA molecule
C) initiation of a new RNA molecule
D) initiation of a new polypeptide chain

__17) _____ marks the end of a gene and causes transcription to stop.
A) RNA polymerase
B) RNA ligase
C) A terminator
D) Methionine

__18) Where do transcription and translation occur in prokaryotic cells?
A) on the plasma membrane
B) in the nucleus
C) in the cytoplasm
D) in chromatophores

__19) Which of the following statements about eukaryotic RNA is *true*?
A) Introns are added to the RNA.
B) Exons are spliced together.
C) A small cap of extra nucleotides is added to both ends of the RNA.
D) The modified RNA molecule is transported into the nucleus.

__20) RNA splicing involves the -
A) addition of a nucleotide "cap" to the molecule.
B) addition of a nucleotide "tail" to the molecule.
C) removal of introns from the molecule.
D) removal of exons from the molecule.

__21) The coding regions of a gene (portions that are EXpressed as polypeptide sequences) are called -
A) introns.
B) EXons.
C) redundant coding sections.
D) proto-oncogenes.

__22) A poly-A sequence is added at the _____.
A) 5' end of a transcript in the nucleus
B) 5' end of a transcript in the cytoplasm
C) 3'-end of a transcript in the nucleus
D) 3'-end of a transcript in the cytoplasm

__23) What would happen if the 5' methyl guanosine cap was not added to an mRNA?
A) The transcript would degrade when the mRNA moves out of the nucleus to the cytoplasm.
B) The mRNA molecule would stabilize and start the process of translation within the nucleus of the cell.
C) The mRNA molecule would move out of the nucleus and create more copies of the mRNA molecule.
D) The mRNA molecule would not be able to add the poly-A tail on its strand at the 5' end.

__24) Where are the RNA components of ribosomes synthesized?
A) cytoplasm
B) nucleus
C) endoplasmic reticulum
D) nucleolus

__25) In prokaryotic cells, ribosomes are found in/on the _____.
A) cytoplasm
B) nucleus
C) mitochondrion
D) endoplasmic reticulum

__26) Which of the following cell structures does not contain heritable information?
A) chloroplast
B) mitochondria
C) Golgi apparatus
D) nucleus

__27) Which of the following is *not* needed in order for translation to occur?
A) DNA template
B) ribosomes
C) tRNA
D) sources of energy, including ATP

__28) Which of the following takes place during translation?
A) the conversion of genetic information from the language of DNA to the language of proteins
B) the conversion of genetic information from DNA nucleotides into RNA nucleotides
C) the conversion of genetic information from the language of proteins to the language of enzymes
D) DNA replication

__29) Which of the following is a function of a tRNA molecule?
A) recognizing the appropriate anticodons in mRNA
B) transferring nucleotides to rRNA
C) helping to translate codons into nucleic acids
D) joining to only one specific type of amino acid

__30) Which of the following options most accurately lists the sequence of events in translation?
A) codon recognition → translocation → peptide bond formation → termination
B) peptide bond formation → codon recognition → translocation → termination
C) codon recognition → peptide bond formation → translocation → termination
D) codon recognition → peptide bond formation → termination → translocation

__31) Which of the following statements regarding the flow of genetic information is *false*?
A) Polypeptides form proteins that determine the appearance and function of the cell.
B) Eukaryotic mRNA is processed in several ways before export out of the nucleus.
C) Transcription occurs in the cytoplasm of eukaryotic cells.
D) Ribosomes function as factories that coordinate the functioning of mRNA and tRNA.

__32) Any change in the nucleotide sequence of DNA is called -
A) a mutation.
B) a mutagen.
C) a base substitution.
D) an anticodon.

__33) Consider the following sentence: "The dog did not eat." Which of the following variations of this sentence is most like a base substitution mutation?
A) The dog did not et.
B) The dog dog did not eat.
C) The did dog not eat.
D) The doe did not eat.

__34) Consider the following sentence: "The dog did not eat." Which of the following variations of this sentence is most like a reading frame mutation?
A) The did dog not eat.
B) The dod idn ote at.
C) The did not eat.
D) The dog did dog did not eat.

__35) A physical or chemical agent that changes the nucleotide sequence of DNA is called a(n) -
A) terminator.
B) transposon.
C) mutagen.
D) anticodon.