Eukaryotic Gene Expression Practice Problems

Class Work

1. Explain the central dogma of cell biology.
2. What is gene expression?
3. Transcription is the process of copying a sequence of DNA into a complementary strand of RNA. Number the events of transcription in order:
   
   ____ RNA polymerase attaches at the promoter sequence on DNA
   ____ The new RNA strand separates from DNA.
   ____ RNA polymerase reaches a stop sequence and falls off the DNA.
   ____ RNA polymerase moves down the DNA while unwinding it and reads the bases of DNA and brings in the new complementary RNA bases.
   ____ The DNA strands reform their double helix.

4. Translation is the process by which the mRNA code is used to create a protein. Number the events of translation in order:

   ____ Each new tRNA moves from the A site to the P site and then leaves the ribosome.

   ____ The tRNA with the anticodon for AUG enters the A site and delivers the amino acid methionine.

   ____ The mRNA becomes sandwiched between the large and small subunits of the ribosome at the start codon.

   ____ Termination occurs when the ribosome reaches a stop codon. The ribosome subunits separate from the mRNA and the protein is released

   ____ The first tRNA leaves the ribosome so the next tRNA can enter.

   ____ The ribosome uses energy to move the mRNA and new amino acids are continuously added by new tRNA molecules.
5. What roles do proteins play in a cell?
6. In both eukaryotes and prokaryotes, DNA is packaged to facilitate replication and transcription. Compare and contrast the location and packaging of DNA in prokaryotes and eukaryotes.
7. How do prokaryotes regulate gene expression?
8. Why do eukaryotes exhibit complex regulation of their genes?
9. If a muscle cell and a brain cell from the same organism contain the exact same genome, why do muscles cells and brain cells differ in structure and function?
10. What do chromatin modifying enzymes do?
11. What are transcription factors?
12. How do transcription factors regulate transcription of a gene?

Homework
13. What is cell specialization?
14. How does gene expression in eukaryotes differ from gene expression in prokaryotes?
15. Describe the role of each type of protein in regulating eukaryotic transcription:
   a. Chromatin modifying enzymes:
   b. RNA polymerase:
   c. Transcription Factors:
16. In prokaryotes, sequences of DNA called operons regulate transcription by turning genes on and off in response to the chemical environment of the cell. By what mechanism do eukaryotes regulate transcription in response to external stimuli?

Class Work
17. What is pre-mRNA?
18. Where does pre-mRNA modification occur?
19. In pre-mRNA modification, what molecule is added to the 5’ end of the pre-mRNA?
20. What molecules are added to the 3’ end of a pre-mRNA strand?
21. Describe 3 functions of the previously mentioned pre-mRNA modifications.
22. What are the noncoding regions of pre-mRNA called?
23. What are exons?
24. How does RNA splicing create an mRNA molecule with a continuous coding sequence?
25. What is a nuclear pore?
26. What is one factor that determines how long an mRNA molecule survives in the cytoplasm before it is degraded by hydrolytic enzymes?
27. What happens to an unused or damaged protein?
Homework

28. During mRNA processing, what molecules are added to the pre-mRNA strand?
29. If the previous modifications were not made, would the mRNA be able to exit the nucleus. Why or why not?
30. Differentiate between exons and introns.
31. Describe the process of RNA splicing.
32. How does alternative splicing facilitate the production of different proteins from the same mRNA strand?
33. Which organelle is responsible for labeling proteins with carbohydrate “tags” that determine the ultimate fate of the protein?

Class Work

34. What is a mutation?
35. Describe each of the following types of gene mutations
   a. Substitution:
   b. Deletion:
   c. Insertion
36. Which type(s) of mutation can alter the reading frame of a gene sequence?
37. What is junk DNA?
38. Describe two examples of silent mutations.
39. How might a mutation be beneficial to an organism?
40. What are mutagens?
41. What is a spontaneous mutation?

Homework

42. A-E below are examples of alterations to the original DNA sequence above. Identify the type of each mutation and explain whether or not the protein will likely be affected.
   A). GGAAGTATCTTCTTTTG
   B). GGAGTTTCGTCTTTTG
   C). GGAGTAT GTCTTTTG
   D). GGAGTGTCGTCTTTTG
   E). GGAGTATCGTCTATG

42. Would a base substitution mutation that alters the mRNA sequence of an intron have any effect on the end protein product? Why or why not?
43. What are five examples of mutagens?
44. Why do some types of gene mutations cause greater changes in proteins than others?
45. Describe two diseases caused by gene mutations.
Free Response

1. Eukaryotic gene regulation is more complex than prokaryotic gene regulation.
   a. Describe how DNA packaging in eukaryotes differs from DNA packaging in prokaryotes, and explain the pre-transcriptional factors that regulate gene expression.
   b. Explain how selective gene expression results in highly specialized cells within eukaryotic organisms.

2. Describe all of the post-transcriptional modifications mRNA undergoes before it leaves the nucleus of the cell.

3. A mutation is a permanent change to the DNA sequence.
   a. Describe the two major causes of gene mutations.
   b. Describe three different types of gene mutations and how they can alter the protein product.

4. Discuss what effect a mutation in each type of gene listed below would have on the protein product and how this might affect the cell.
   a. A substitution mutation in an intron.
   b. An insertion mutation in the region of DNA that binds to a transcription factor.
   c. A deletion in a gene that codes for a chromatin modifying enzyme.
Eukaryotic Gene Expression Answers

Class Work
1. DNA is transcribed into RNA and RNA is translated into protein. The central dogma describes the flow of information from gene sequence to protein product.
2. Gene expression is the process by which DNA directs protein synthesis.
3. 1, 4, 3, 2, 5
4. 3, 2, 5, 6, 1, 4
5. Proteins make up much of the physics structure of an organism and are the molecular machines that direct the form and function of a cell. They act as enzymes that facilitate chemical reactions, prove structure and support, and facilitate the cell-to-cell and intracellular communication necessary for complex eukaryotic organisms to function properly.
6. In Prokaryotes DNA is packaged in a chromosome located in the cytoplasm. In Eukaryotes DNA is packaged in chromatin form within the nucleus of the cell. Eukaryotic DNA is tightly wrapped around histone proteins to form nucleosomes that are tightly packed together to prevent DNA segments from being exposed preventing gene expression from occurring until the cell signals it to begin.
7. Prokaryotes regulate gene expression by using operons that turn genes on and off in response to the chemical environment of the cell. The lac operon is a previously discussed example.
8. Eukaryotes exhibit complex regulation of their genes because they have much more complex cellular packaging. Eukaryotes contain many different types of highly specialized cells that must work together for the survival of the organism. This cell specialization means that different parts of the genome will be used to express different and highly specific types of proteins.
9. All cells in a eukaryotic organism (with the exception of reproductive cells) contain the same genome. However, not all the genes in the genome are expressed in each cell. Muscle cells and brain cells have very different structures and perform different functions because different genes are expressed in each type of cell to produce the type of proteins each cell needs to function.
10. Chromatin modifying enzymes bind to portions of the chromatin in the DNA of eukaryotes and unwind DNA from histone proteins in order to expose the appropriate nucleotide sequences for gene expression.
11. Transcription factors are proteins that regulate RNA transcription.
12. Transcription factors can bind to the DNA sequences near the promoter region of a gene, which signals RNA polymerase to begin RNA transcription. Transcription factors can be produced in the cell in response to chemical cues from the external environment.

13. In complex eukaryotic organism, different types of cells contain different structures to support different and highly specific functions that contribute to the overall survival of the organism. In humans, muscle cells, skin cells, and brain cells are all examples of specialized cells that express different genes in order to produce proteins that allow the cell to perform a specific role.

14. Both prokaryotes and eukaryotes regulate gene expression, but eukaryotic gene expression is more complex because of the structure of eukaryotic chromatin and the complexity of eukaryotic cell specialization.

15. a. Chromatin modifying enzymes: bind to chromatin and unwind the DNA from histone proteins allowing gene to be transcribed.
   b. RNA polymerase: binds to a DNA molecule and transcribes DNA into mRNA.
   c. Transcription Factors: respond to external stimuli and bind to specific regions of DNA near the promoter sequence of a gene, which signals RNA transcription to begin.

16. Transcription factors are proteins that bind to promoter regions of DNA and signal RNA polymerase to begin transcription. Transcription factors are produced in response to cues from the external environment of a cell, allowing different cells within an organism to communicate and respond to external cues.

17. Pre-mRNA is the original RNA transcript produced in eukaryotic cells, but before pre-mRNA can leave the nucleus and be translated it needs to be modified.

18. Pre-mRNA modification occurs within the nucleus of the cell immediately following transcription.

19. A modified guanine molecule called the 5’ cap is added to the 5’ end of the pre-mRNA molecule.

20. A series of adenosine (A) nucleotides called the poly-A tail are added to the 3’ end of the pre-mRNA strand.
21. The 5’ cap and 3’ poly-A tail facilitate the export of mRNA from the nucleus to the cytoplasm, protect mRNA from degradation from hydrolytic enzymes in the cytoplasm, and direct ribosomes to attach to the RNA to begin the process of translation.

22. Noncoding regions of pre-mRNA are called introns.

23. Exons are the coding regions of pre-mRNA that will be spliced together to form the mature mRNA molecule that will be expressed – translated into a protein.

24. A pre-mRNA molecule contains noncoding regions of DNA adjoined to coding regions. RNA splicing removes the introns and joins the exons together to create an mRNA molecule with a continuous coding sequence.

25. A nuclear pore is a protein structure that controls the flow of molecules from the nucleus and ensures only mRNAs with a proper 5’ cap and 3’ poly-A tail can exit the nucleus and enter the cytoplasm.

26. The longer the poly-A tail, the longer an mRNA molecule will survive in the cytoplasm.

27. Hydrolytic enzymes degrade unused or damaged proteins.

Homework

28. During mRNA processing a modified guanine cap is added to the 5’ end of the mRNA molecule and a poly-A tail is added to the 3’ end of the molecule.

29. No, the nuclear does not allow mRNA molecules without these modifications to pass through it.

30. Exons are the coding regions of mRNA that expressed by the cell. The introns are the segments of noncoding regions that must be cut out during RNA splicing to create an mRNA molecule with a continuous coding sequence.

31. In a pre-mRNA molecule coding and noncoding regions of mRNA are adjacent to one another. RNA splicing removes the introns or noncoding regions of DNA and joins together exons, or the coding region that is going to be expressed by the cell.

32. Alternative splicing allows for different portions of the exact same gene sequence to be expressed because different regions of the mRNA are treated as exons, which results in a different coding sequence, and, therefore, production of a different protein.

33. The endoplasmic reticulum can create glycoproteins by tagging proteins with a carbohydrate molecule.

Class Work

34. A mutation is a permanent change in the DNA sequence of a gene.
35. Substitution: a substitution mutation occurs when different nucleotide base is substituted for original nucleotide.

b. Deletion: a deletion mutation occurs when a nucleotide is deleted from the original sequence.

c. Insertion: an insertion mutation occurs when a nucleotide is inserted into the original sequence.

36. Insertions and deletions are most likely to alter the reading frame because addition or subtraction of a nucleotide base changes the way ribosomes “read” the 3-letter codon sequence that codes for the amino acids.

37. Junk DNA is DNA within the genome that does not code for proteins.

38. Silent mutations can occur in a region of junk DNA or a noncoding region of a gene (intron) that does not affect RNA splicing. A silent mutation can occur when a substitution mutation alters the 3rd base of a codon, but does not change the amino acid sequence of a protein.

39. If a mutation results in a trait that allows the organism to better survive in its environment and reproduce, it is considered a beneficial mutation.

40. Mutagens are agents that cause mutations. Humans are exposed to a variety of chemicals and sources of radiation that can cause mutations.

41. A spontaneous mutation is an alteration of nucleotides within the cell that occurs randomly, typically during replication.

Homework
DNA sequence: GGA-GTA-TCG-TCT-TTG
RNA transcript: CCU-CAU-AGC-AGA-AAC
Amino Acid Sequence: Pro-His-Ser-Arg-Asn

42. A). GGAAATCTTTTTTG (insertion – yes)
B). GGAGTTTCGTCTTTTG (substitution – yes:
C). GGAGTTGTCTTTTG (deletion – yes)
D). GGAGTTGCTCTTTTG (substitution – no)
E). GGAGTATCGTCTATG (substitution-yes, insert stop)

43. A substitution mutation in an intron would not alter the protein product because introns are not expressed and a substitution mutation would not alter where the RNA splicing occurs.

44. Five examples of mutagens are X-rays, UV light, bromine, benzene, and nitrous acid (see notes for others).
45. Some types of gene mutations alter which amino acids are coded for, which changes the protein structure and function dramatically. Other mutations can be silent, meaning that although they change the nucleotide sequence of a gene, they do not affect protein production.

46. Sickle cell anemia is caused by a substitution mutation. Tay-Sachs disease is a result of insertion and deletion mutations.

Free Response

1. a. In prokaryotes DNA is packaged in a chromosome and located in the cytoplasm of the cell. Regions of DNA called operons respond to chemical signals in the cell and direct which genes will be transcribed. In eukaryotes DNA is wrapped around histone proteins to form nucleosomes that are compacted into chromatin fiber. The genes must be unwound by chromatin modifying enzymes and exposed to RNA polymerase in order for transcription to begin. Transcription factors are proteins that help regulate gene expression by bonding to regions of DNA near the promoter region and direction the start of transcription. Transcription factors can be produced in response to external stimuli, which allows the cell to express genes needed for it to function as a contributing part of a whole in complex organisms.

b. All cells in a eukaryotic organism contain a complete genome. Selective gene expression allows cells to selectively express genes that will produce the types of proteins the cell needs to perform specific functions. Muscle cells and brain cells, for example, have very different structures and perform different functions because they express different genes.

2. Addition of 5’ cap and 3’ poly A tail: a series of adenosine (A) nucleotides called the poly-A tail are added to the 3’ end of the pre-mRNA strand. The 5’ cap and 3’ poly-A tail facilitate the export of mRNA from the nucleus to the cytoplasm, protect mRNA from degradation from hydrolytic enzymes in the cytoplasm, and direct ribosomes to attach to the RNA to begin the process of translation. RNA splicing: in a pre-mRNA molecule coding and noncoding regions of mRNA are adjacent to one another. RNA splicing removes the introns or noncoding regions of DNA and joins together exons, or the coding region that is going to be expressed by the cell.
3. a. Describe mutagens and spontaneous mutations
   b. Substitution: a substitution mutation occurs when different nucleotide base is substituted for original nucleotide. Substitution mutations can have no effect on the protein product, if the substitution occurs in a noncoding region or does not change the amino acid sequence. Substitution mutations can also dramatically alter the amino acid sequence if it results a stop codon.
   Deletion: a deletion mutation occurs when a nucleotide is deleted from the original sequence. A deletion mutation can shift the reading frame and dramatically alter the protein product.
   Insertion: an insertion mutation occurs when a nucleotide is inserted into the original sequence. An insertion mutation can also shift the reading frame during translation and alter the protein product.

4. a. A substitution mutation in an intron would likely have no effect on the protein product and, therefore, would not alter the function of the cell.
   b. A mutation in this region of DNA would likely prevent the transcription factor from binding to the DNA, which would in turn prevent the gene from transcribing a protein the cell needs to function properly.
   c. A deletion in a gene that codes for a chromatin modifying enzyme would likely disrupt the production of the enzyme. Without this enzyme, portions of DNA would not be exposed for transcription.