

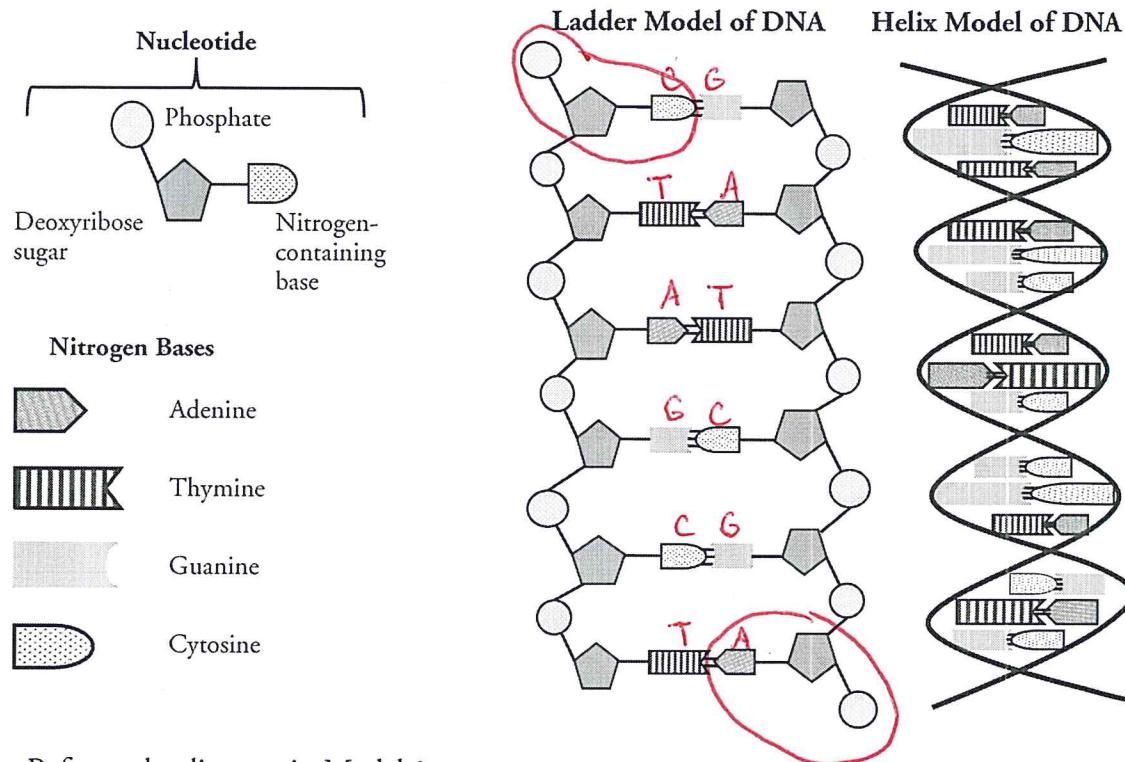
DNA Structure and Replication

How is genetic information stored and copied?

Why?

Deoxyribonucleic acid or **DNA** is the molecule of heredity. It contains the genetic blueprint for life. For organisms to grow and repair damaged cells, each cell must be capable of accurately copying itself. So how does the structure of DNA allow it to copy itself so accurately?

Model 1 – The Structure of DNA



- Refer to the diagram in Model 1.

- What are the three parts of a nucleotide?

Deoxyribose sugar, phosphate, nitrogen containing base

- What kind of sugar is found in a nucleotide?

deoxyribose

- Which nucleotide component contains nitrogen?

nitrogen containing base

- Name the four nitrogen bases shown in Model 1.

A T C G

- DNA is often drawn in a "ladder model." Locate this drawing in Model 1.

- Circle a single nucleotide on each side of the ladder model of DNA.

See picture

- b. What part(s) of the nucleotides make up the rungs of the “ladder”?

nitrogen bases

- c. What parts of the nucleotides make up the sides (backbone) of the “ladder”?

sugars and phosphates

- d. Look at the bottom and top of the “ladder” in Model 1. Are the rungs **parallel** (the ends of the strands match) or **antiparallel** (the ends of the strands are opposites)?

antiparallel

3. On the ladder model of DNA label each of the bases with the letter A, T, C or G.

see picture

4. Refer to Model 1. When one nucleotide contains adenine, what type of base is the adenine attached to on the opposite nucleotide strand?

T

5. The two strands of DNA are held together with **hydrogen bonds** between the nitrogen bases. These are weak bonds between polar molecules. How many hydrogen bonds connect the two bases from Question 4?

2

6. Refer to Model 1. When one nucleotide contains cytosine, what type of base is the cytosine attached to on the opposite nucleotide strand?

G

7. How many hydrogen bonds connect the two bases from Question 6?

3

8. With your group, use a complete sentence to write a rule for how the bases are arranged in the ladder model of DNA.

The bases A and T bind together, as do C and G.



Read This!

Erwin Chargaff (1905–2002), an Austrian-American biochemist, investigated the ratio of nucleotide bases found in the DNA from a variety of organisms. From his research, as well as research by Rosalind Franklin and Maurice Wilkins, Watson and Crick developed the **complementary base-pair** rule during their race to discover the structure of DNA. The complementary base-pair rule states that adenine and thymine form pairs across two strands, and guanine and cytosine form pairs across two strands.

9. Fill in the **complementary** bases on the strand below according to the base-pair rule.

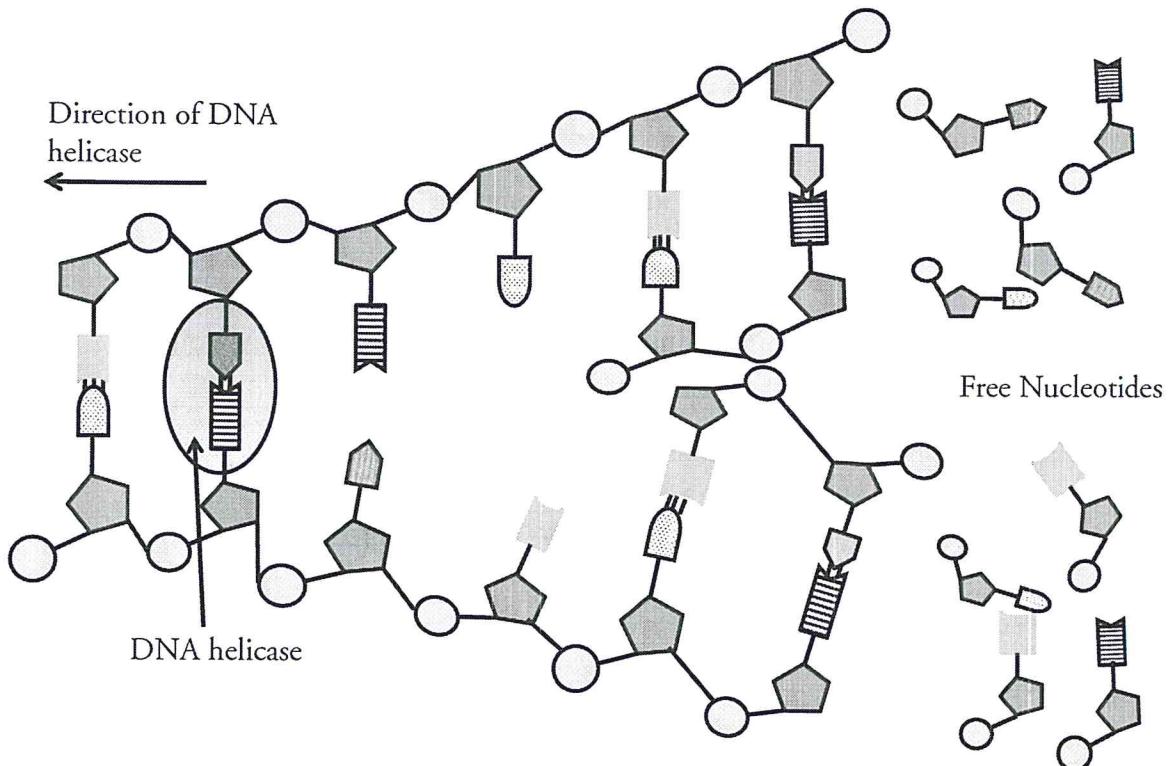
A T C C A G
T A G G T C

10. The ladder model of DNA is a simplified representation of the actual structure and shape of a DNA molecule. In reality, the strands of DNA form a **double helix**. Refer to the double helix diagram in Model 1 and describe its shape using a complete sentence.

It is a twisted ladder.



Model 2 – DNA Replication



11. Examine Model 2. Number the steps below in order to describe the replication of DNA in a cell.

- 4 Hydrogen bonds between nucleotides form.
- 1 Hydrogen bonds between nucleotides break.
- 2 Strands of DNA separate.
- 3 Free nucleotides are attracted to exposed bases on the loose strands of DNA.

12. Locate the DNA helicase on Model 2.

- a. What type of biological molecule is DNA helicase?

enzyme

- b. What is the role of DNA helicase in the replication of DNA?

to break hydrogen bonds to open the helix

13. What rule is used to join the free nucleotides to the exposed bases of the DNA?

Chargaff's rule

14. This type of replication is called **semi-conservative replication**. Considering the meaning of these words (semi—half; conserve—to keep), explain why DNA replication is called semi-conservative.

Half of the original DNA is conserved in each new DNA piece

15. DNA molecules can be tens of thousands of base pairs in length. Mistakes in DNA replication lead to mutations, which may or may not be harmful to an organism. How does semi-conservative replication help prevent mutations during DNA replication?

*There is an original strand to act as a template
plus there is a strand to proofread against*

16. The proportions of the bases are consistent within a species; however they do vary between species. Using the base-pair rules, complete the following table to show the percentage of each type of base in the five different organisms.

Organism	Percentage of each type of base			
	Adenine	Guanine	Cytosine	Thymine
Human	31	19	19	31
Cow	28	22	22	28
Salmon	29	21	21	29
Wheat	27	23	23	27
Yeast	31	19	19	31

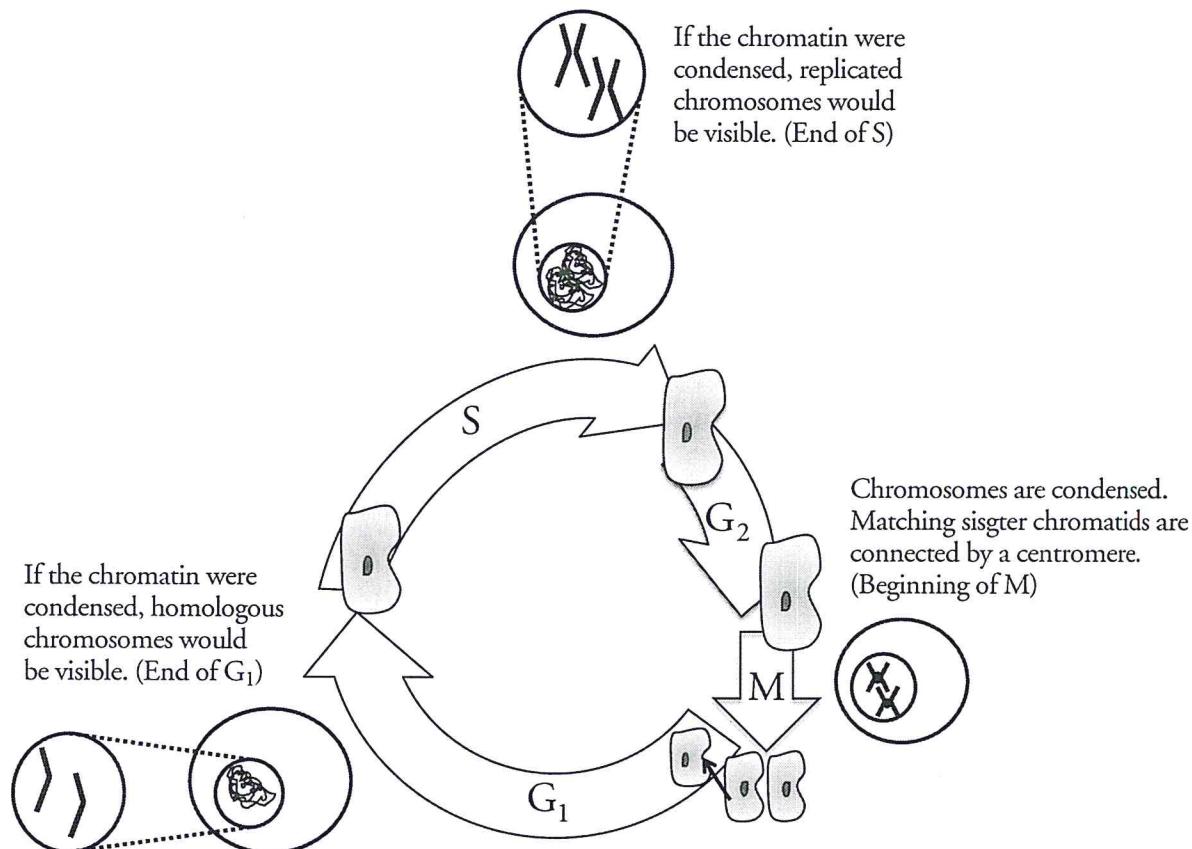


*A must equal T
C must equal G*

$$A + T + C + G = 100\%$$

Extension Questions

Model 3 – Timing of DNA Replication



17. According to Model 3, what term refers to loose DNA inside of a nucleus?

chromatin

18. During what part of the cell cycle is the DNA in a cell's nucleus replicated?

S

19. During what part of the cell cycle is the DNA in a cell condensed into chromosomes?

M

20. Replicated chromosomes are often illustrated as an X shape to match how they look in real life just before cell division.

- a. According to Model 3, which of the following diagrams correctly show an original set of homologous chromosomes (grey) and their sister chromatids (black)—the replicated portion?



- b. What structure holds the two sister chromatids together as they prepare for cell division?

Centromere

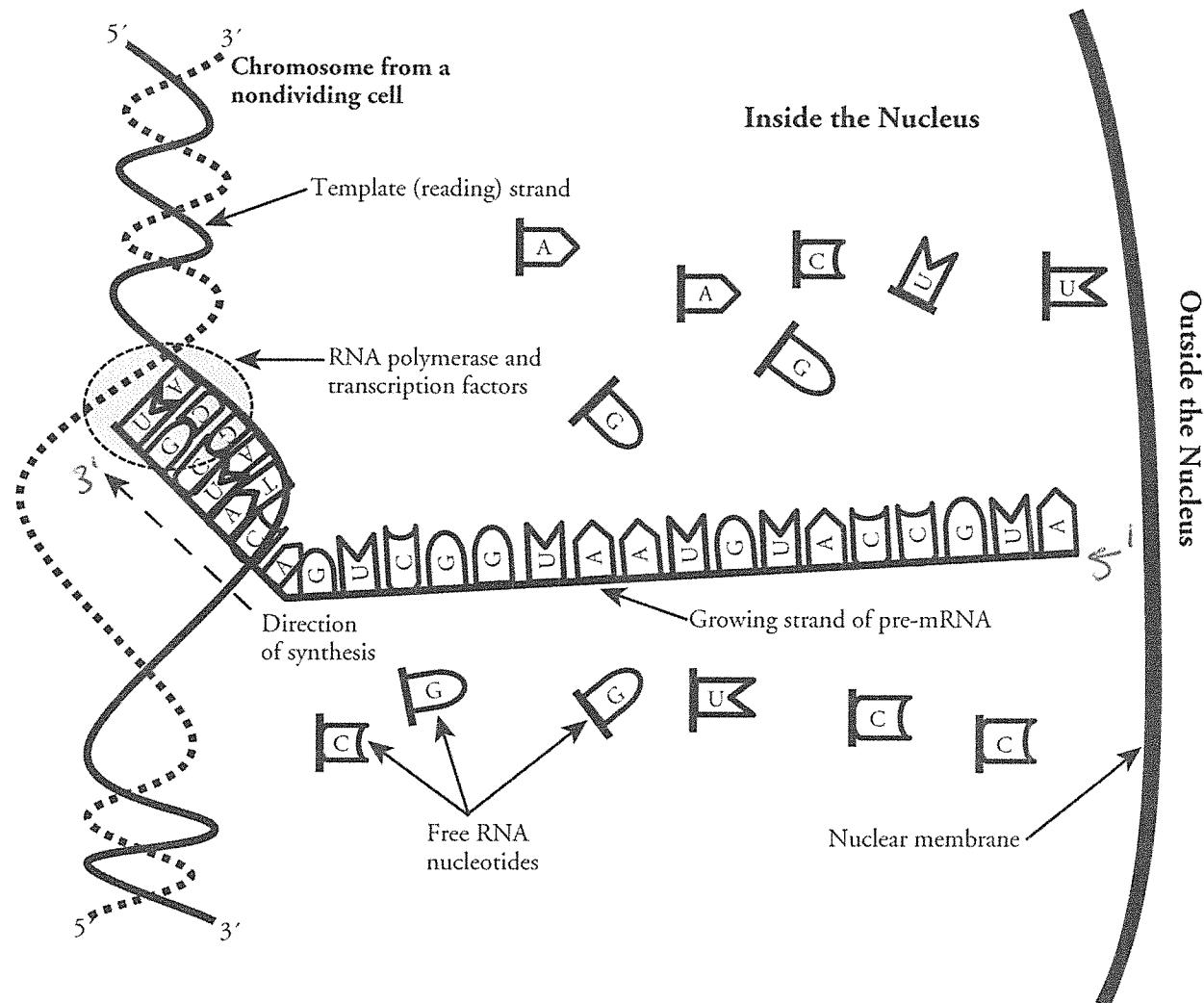
Gene Expression—Transcription

How is mRNA synthesized and what message does it carry?

Why?

DNA is often referred to as a genetic blueprint. In the same way that blueprints contain the instructions for construction of a building, the DNA found inside the nuclei of cells contains the instructions for assembling a living organism. The DNA blueprint carries its instructions in the form of genes. In most cases the genes direct the production of a polypeptide, from which other more complex proteins, such as enzymes or hormones, may be constructed. These polypeptides and other molecules run the organism's metabolism and, in multicellular organisms, dictate what each cell's job is. So, what is the language of these instructions and how are they read and decoded by the cellular organelles? This activity will focus on the decoding of genes in eukaryotes.

Model 1 – Transcription



1. Consider the eukaryotic cell in Model 1.

- a. Where in the cell is the DNA found?

nucleus

- b. Where in the cell does transcription take place?

nucleus

2. Refer to Model 1.

- a. What polymer is synthesized during transcription?

mRNA

- b. What monomers are used to construct this polymer and where are they found?

Free RNA nucleotides - free-floating in nucleus

3. According to Model 1, what enzyme is required for transcription? (Hint: Think about how enzymes are named. What ending is used for enzyme names?)

RNA polymerase

4. Refer to Model 1.

- a. What is the base-pair rule for a DNA strand matching an RNA strand?

A-U C-G

- b. Compare this base-pair rule with that of two DNA strands.

Instead of A-T (DNA), there is A-U (RNA).
C-G remains the same

5. Which strand of the DNA contains the "blueprint" for the pre-mRNA?

template strand

6. Consider Model 1.

- a. In which direction is the DNA molecule read?

3' to 5"

- b. The DNA strand and pre-mRNA strand are anti-parallel. With this in mind label the 3' and 5' ends of the pre-mRNA strand in Model 1.

- c. In which direction is the pre-mRNA molecule constructed?

See image



7. Before printing presses were available, books had to be transcribed in order to share the information in them. Consider the definition of transcription and explain why the process in Model 1 is described using that word.

make an exact copy

Read This!

In eukaryotes the enzyme **RNA polymerase** joins with several **transcription factor** proteins at the promoter, which is a special sequence of base pairs on the DNA template strand that signals the beginning of a gene. The transcription factor proteins, along with the RNA polymerase, is called the **transcription initiation complex**. This moves along the DNA template strand at about 40 base pairs per second producing pre-mRNA. When the RNA polymerase reaches the **terminator** sequence of base pairs on the DNA template strand, it completes the production of pre-mRNA and releases it into the nucleoplasm.

8. What parts make up the transcription initiation complex?

RNA polymerase and transcription factors

9. Where on the DNA strand does the transcription initiation complex form?

Promotor

10. Nearly all cells in an organism contain identical DNA, and each DNA strand may contain hundreds or thousands of individual genes. Is it likely that a cell would transcribe all the genes within its nucleus simultaneously? Justify your answer using complete sentences.

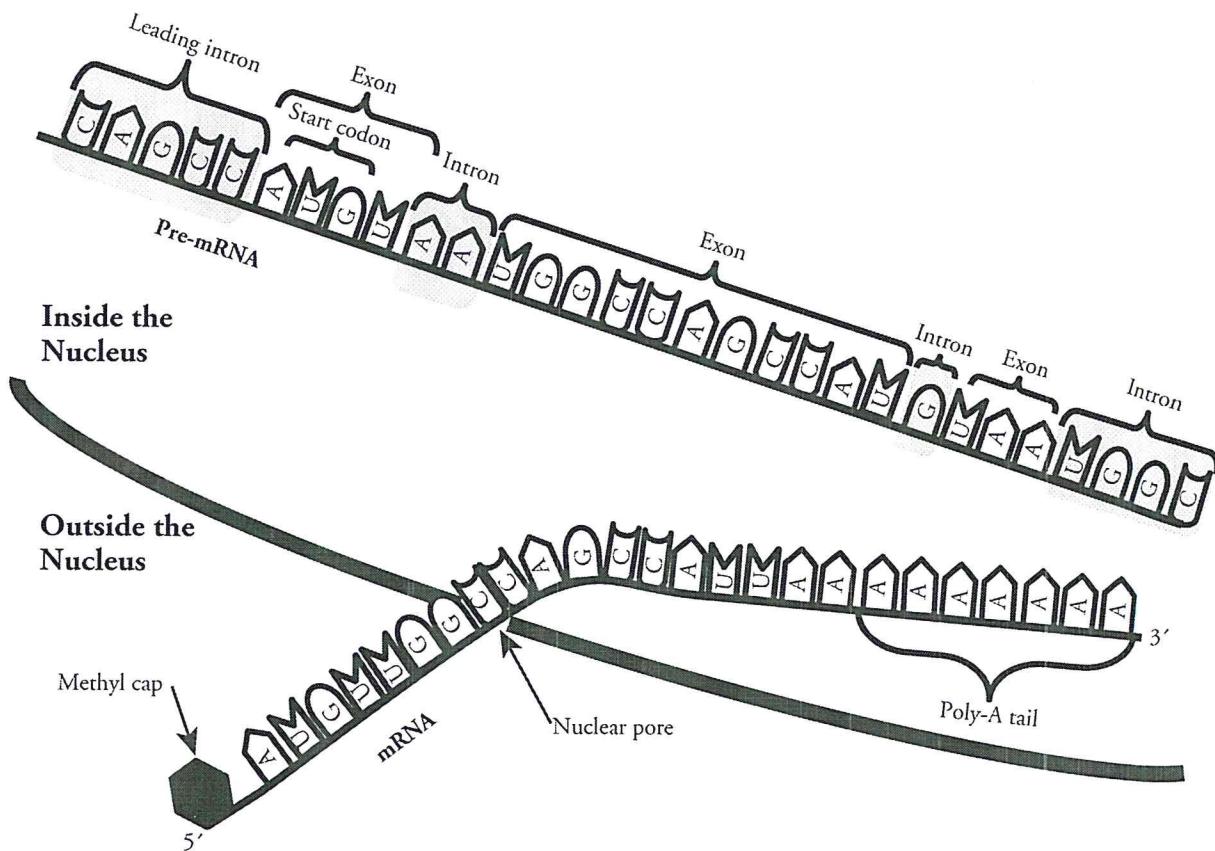
No, the cell only transcribes the genes it needs at any given time.

11. Considering the many types of cells in a multicellular organism, and their different functions, is it likely that all cells transcribe all their genes at some point in their lifetime? Justify your answer using complete sentences.

No, some genes are only used in specific cells



Model 2 – mRNA Processing



12. Compare the pre-mRNA to the mRNA leaving the nucleus in Model 1.

- a. What has been removed from the pre-mRNA to make it into mRNA?

introns

- b. What has been added to the mRNA that was not present in the pre-mRNA, and where on the mRNA strand are the additional items located?

5' methyl cap

3' poly A tail

13. Identify the structure through which the mRNA leaves the nucleus.

nuclear pore

14. The nucleotides on the mRNA will be “read” in the next step to producing a polypeptide. What sequence of bases indicates the starting point for the polypeptide “blueprint”?

AUG

15. The “m” in mRNA is short for “messenger.” Why is this molecule called messenger RNA?

it carries the DNA “message”

Read This!

Introns are sections of pre-mRNA that are noncoding. That is, they don't provide useful information for the production of the polypeptide being synthesized. There is evidence that suggests these introns allow certain sections of DNA to code for different polypeptides when different sections are removed. The removal of specific sections is triggered by a signal response in the cell. The portions of the pre-mRNA that remain are called **exons**. The methyl cap (sometimes called the GTP cap or 5' cap) helps the mRNA molecule move through the nuclear pore and attach to a ribosome, its final destination. mRNA is a short-lived molecule. Once in the cytoplasm the mRNA will be subject to **exonucleases** that immediately start removing individual nucleotides from the 3' end of a nucleic acid. The individual mRNA nucleotides will then be free to be used again during the process of transcription.

16. The human genome contains about 25,000 genes and yet produces about 100,000 different polypeptides. Propose an explanation of how this is possible.

pre-mRNA can be used in more than one way depending on the introns that are removed

17. Using the information in the *Read This!* box, develop a hypothesis to explain the advantage of the poly-A tail added to the 3' end of the mRNA.

It helps protect it from the exonucleases



18. Different mRNA molecules can have poly-A tails of different lengths. Considering the purpose of adding the poly-A tail (from the previous question), why are some tails longer than others? Justify your answer using complete sentences.

The longer the tail, the longer the mRNA lasts, allowing for longer translation.

19. Summarize the steps of transcription.

① make pre-mRNA from DNA with the initiation complex
② cut out introns
③ add 5' cap and 3' poly-A tail

Extension Questions

20. What type of biological molecule is an exonuclease?

enzyme

21. Free nucleotides must be available in a cell's nucleus to produce mRNA strands. Where do these free nucleotides come from?

the cytoplasm - they are recycled pieces from old RNA

22. Even though bacterial cells do not contain a nucleus, transcription occurs in a similar way to eukaryotic cells. How might biologists use transcription mechanisms to support the theory of evolution?

It's the same, so it probably existed very early and was passed down.
It would be very unlikely to have developed just like it did in multiple different organisms.

Gene Expression—Translation

How do cells synthesize polypeptides and convert them to functional proteins?

Why?

The message in your DNA of who you are and how your body works is carried out by cells through gene expression. In most cases this means synthesizing a specific protein to do a specific job. First, mRNA is transcribed from the DNA code. Then, the mRNA sequence is translated into a polypeptide sequence.

Model 1 – Codons

Second Base				Amino acids	
First Base	U	C	A	G	
U	UUU Phe UUC Phe UUA Leu UUG Leu	UCU Ser UCC Ser UCA Ser UCG Ser	UAU Tyr UAC Tyr UAA stop UAG stop	UGU Cys UGC Cys UGA stop UGG Trp	U C A G
	CUU Leu CUC Leu CUA Leu CUG Leu	CCU Pro CCC Pro CCA Pro CCG Pro	CAU His CAC His CAA Gln CAG Gln	CGU Arg CGC Arg CGA Arg CGG Arg	U C A G
	AUU Ile AUC Ile AUA Ile AUG Met (start)	ACU Thr ACC Thr ACA Thr ACG Thr	AAU Asn AAC Asn AAA Lys AAG Lys	AGU Ser AGC Ser AGA Arg AGG Arg	U C A G
	GUU Val GUC Val GUA Val GUG Val	GCU Ala GCC Ala GCA Ala GCG Ala	GAU Asp GAC Asp GAA Glu GAG Glu	GGU Gly GGC Gly GGA Gly GGG Gly	U C A G

1. Model 1 defines the code scientists have discovered that relates the nucleotide sequence of mRNA to the amino acid sequence of polypeptides.

- a. What do the letters U, C, A, and G in Model 1 represent?

nucleotides in mRNA

- b. What do the abbreviations such as Phe, Ile, Ala, and Gly in Model 1 represent?

amino acids

- c. The language of mRNA is often described as a “triplet code.” Explain the significance of this reference.

each 3 letters codes for a specific
amino acid

2. If an mRNA molecule had 300 nucleotides in the coding region of the strand, how many amino acids would be in the polypeptide that was synthesized? Show mathematical work to support your answer.

$$300 / 3 = 100$$

3. Consider the information in Model 1.

- a. How many different **codons** (triplets) code for the amino acid Proline (Pro)?

4

- b. Compare all of the codons for Proline. What are the similarities and differences?

They all start with CC but the third letter varies

- c. Considering that mistakes can occur during transcription and DNA replication, what advantage is there for an organism to have multiple mRNA sequences code for the same amino acid?

You might still get the same amino acid, even if the mRNA wasn't right



4. Using the mRNA codon chart in Model 1, complete the following:

DNA →	TAC	CTT	CGG	ATG	GTC	ACT
mRNA →	AUG	GAA	GCC	UAC	CAG	UGA
polypeptide sequence →	Met (Start)	Glu	Ala	Tyr	Gln	Stop

5. According to the table in Model 1, what amino acid is at the beginning of every polypeptide?

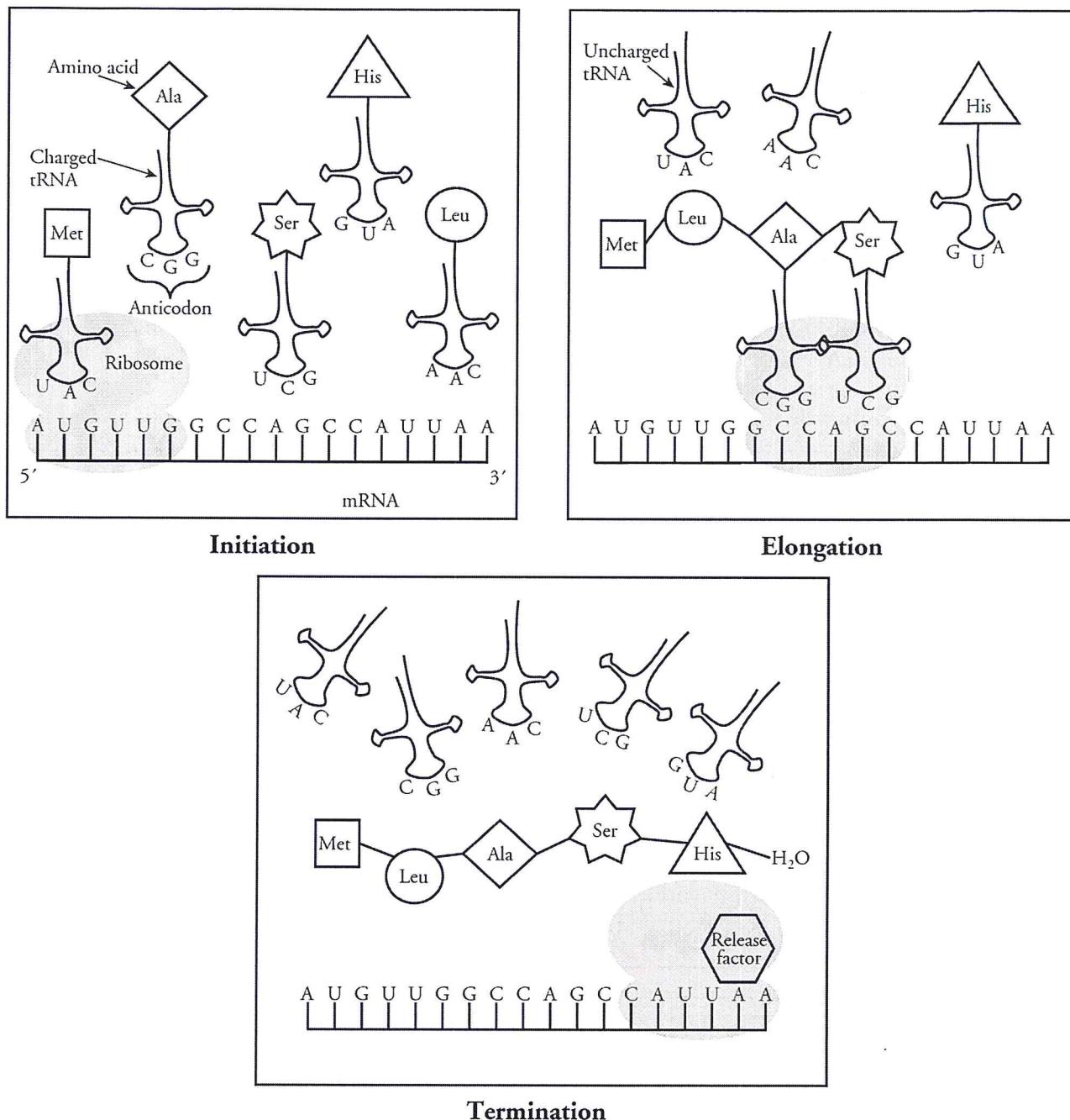
Methionine (Met)

6. The codons shown in Model 1 are used in all species on Earth with very little variation. What might scientists conclude from this?

This supports evolution - the system developed early on and all organisms are descended from that early organism



Model 2 – Translation



7. Refer to Model 2.

a. What are the three stages of translation?

Initiation, Elongation, termination

b. Define each of the terms used in your answer to part a as they are used in everyday language.

Initiation - the start

Elongation - to make longer, to add on to

Termination - to stop

8. According to Model 2, when the mRNA leaves the nucleus, to which cellular organelle does it attach?

ribosome

9. The mRNA attaches to the organelle at the sequence AUG. What is the significance of this sequence of nucleotides?

"Start" codon

10. Describe the movement of the ribosome as translation occurs.

it moves from the 5' to 3' end of the mRNA

Read This!

The ribosome is a large complex of ribosomal RNA (rRNA) and proteins. It consists of two subunits. The smaller subunit binds to the mRNA strand and the larger subunit holds the tRNA molecules in place while the covalent peptide bond is formed between the amino acids. Several ribosomes can attach to an mRNA molecule simultaneously. This allows for many polypeptide chains to be synthesized at once.



11. The tRNA molecules in a cell are short sequences of nucleotides (about 80 bases) that contain an **anticodon** and carry a specific amino acid.

- a. Find the tRNA in Model 2 that is carrying the Histidine (His). What sequence of nucleotides makes the anticodon on this tRNA molecule?

GUU

- b. What codon on mRNA would match this anticodon?

CAU

- c. Verify that the codon you wrote in part b codes to Histidine by looking at the table in Model 1.

- d. What anticodon would be found on a tRNA molecule carrying Glycine (Gly)? (Note: There are several correct answers here.)

mRNA	GGU	or	GGA	or	GGC	or	GGG
tRNA	CCA		CCU		CCG		CCC

12. The "t" in tRNA is short for transfer. In a complete sentence, explain why this molecule is called transfer RNA.

it transfers amino acids to build a protein

13. During elongation, how many tRNA molecules are held in the ribosome at the same time?

2

14. What will happen to the unattached tRNA once it has delivered its amino acid?

it is released and will find another amino acid

15. Describe two things that occur during termination as illustrated in Model 2.

a release factor binds

and a water molecule is added to the
amino acid chain

16. Explain how the term "translation" applies to the synthesis of proteins from DNA instructions.

The genetic code is being translated into protein



Extension Questions

17. The codons of mRNA are a set of three nucleotides with four possible bases in combination.

a. Show mathematically that there are 64 permutations possible when three bases are used.

$$4 \times 4 \times 4 = 64 \quad (4 \text{ possibilities for the } 1^{\text{st}} \text{ base} \\ 2^{\text{nd}} \text{ base} \\ 3^{\text{rd}} \text{ base})$$

b. Show mathematically that two bases as a codon would not be sufficient to code for all 20 known amino acids.

$$4 \times 4 = 16 \quad \text{There are 20 amino acids and stop. } 16 < 20$$

18. A silent mutation is one that does not affect protein structure. Write a code for an original DNA strand containing at least 12 bases, and then mutate the original DNA so that the final protein is unaffected.

DNA	TTT C GAG AC AAA
RNA	AAAG CUC UG UUU
Amino acids	Lys Ala Leu Lys

mutated DNA that doesn't change the amino acids

DNA	TTC CGA GAC AAA
RNA	AAG GCU CUG UUU
Amino acids	Lys Ala Leu Lys

19. In prokaryotic cells, translation begins before transcription is finished. Give two reasons why this would not be possible in eukaryotic cells.

- (1) The nucleus physically separates the two processes.
- (2) Eukaryotic DNA must be edited - have introns removed, 3' tail and 5' cap added