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Module 2—Continuity and Unity of Life

Lesson 1

Genes and Protein Synthesis

3.1.9-12.A

Proteins are vital to the functioning of cells. Nearly all cellular processes require proteins. Proteins are also important structural components of cells, and they play a role in cellular communication. To build proteins, the cell uses instructions contained in molecules of **deoxyribonucleic acid,** or **DNA.** Just as the blueprint for a building describes how to build the building, DNA is a blueprint that describes how to "build" a protein.

Deoxyribonucleic acid, or **DNA,** is the molecule that stores genetic information in living things.

Nucleotides are the subunits that make up DNA. Each nucleotide consists of a sugar, a phosphate group, and a nitrogen base that varies among nucleotides.

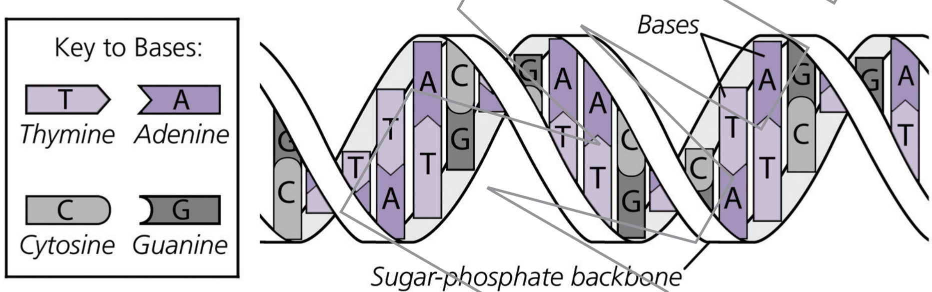
The ***complementary base pairing rules*** state that base A pairs with T and C pairs with G.

Hydrogen bonds between nitrogen bases hold two DNA strands together as a double strand.

A ***codon*** is a sequence of three nucleotide bases that codes for a specific amino acid.

DNA, Genes, and Chromosomes

A DNA molecule is a long polymer chain made up of *nucleotides.* Nucleotides are molecules composed of carbon, hydrogen, and oxygen. In addition, they contain nitrogen and phosphorus. Each nucleotide contains one of four nitrogen bases: adenine (A), cytosine (C), guanine (G), and thymine (T). DNA is usually found in the form of a double strand, made up of two molecules joined by bonds between the bases. The DNA bases can bond only in specific ways: adenine bonds only with thymine, and cytosine bonds only with guanine. These bonding rules are called *complementary base pairing rules.*



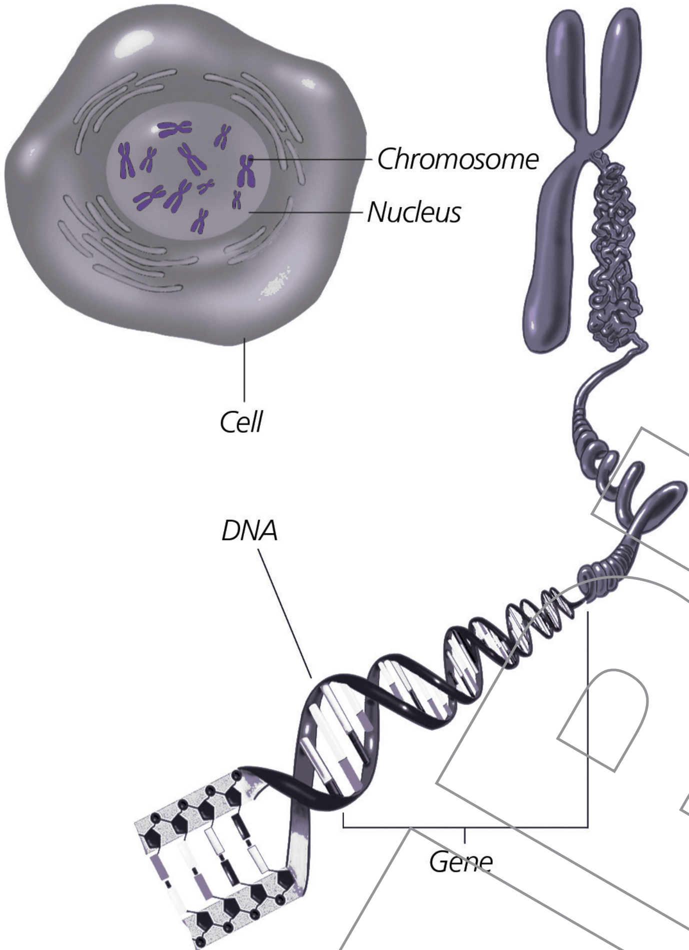
The two strands of DNA are joined by complementary base pairing.

The bases of DNA make up nucleotide sequences. These sequences are called **genes.** Genes carry the instructions for making certain proteins and functional molecules for the body. The process by which genetic information is used to make a protein is called *gene expression.*

Genes are found on **chromosomes,** which are in the nucleus of eukaryotic cells. Chromosomes are made up of DNA that is tightly wound around proteins called *histones.*

A **gene** is a stretch of DNA that contains the information needed to make a protein.

A **chromosome** is a single piece of DNA, made up of genes.



Chromosomes are found in the nucleus of the cell.

Every living thing has its own *genetic code*. A genetic code is created when DNA is translated to an amino acid sequence.

What are regions of DNA that code for proteins?

A bases

B genes

C nucleotides

D chromosomes

Bases are adenine, cytosine, guanine, and thymine, and together with a sugar and phosphate group, they form a nucleotide. DNA forms chromosomes as it winds itself around histones. Genes are regions of DNA that code for proteins, so the correct answer is B.

Although species differ in many of their genes, the *genetic code* is the same for nearly all the organisms on Earth. This is evidence for a common origin for all life.

Transcription: From DNA to RNA

In eukaryotes, DNA is located inside the nuclei of cells, but proteins are assembled in the cytoplasm outside the nucleus. Although DNA carries the instructions for making proteins, it does not leave the nucleus. Instead, the information contained in DNA is copied, and a "transcript" of the information moves out into the cytoplasm. This transcript is a molecule of *ribonucleic acid,* or *RNA.*

RNA is similar in structure to DNA; it is also made up of nucleotides. An RNA molecule, however, is made up of only one strand of nucleotides. Another difference between DNA and RNA is that RNA does not contain the base thymine. Instead, it contains uracil (U). Like thymine, uracil bonds only to adenine.

There are three main types of RNA: messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA). Messenger RNA (mRNA) copies the information in the DNA molecule in the nucleus. The process in which information in DNA is copied is called **transcription.**

Before transcription begins, specific proteins separate the two strands of the DNA molecule. The bonds between the bases break, but the backbone of the DNA molecule remains intact.

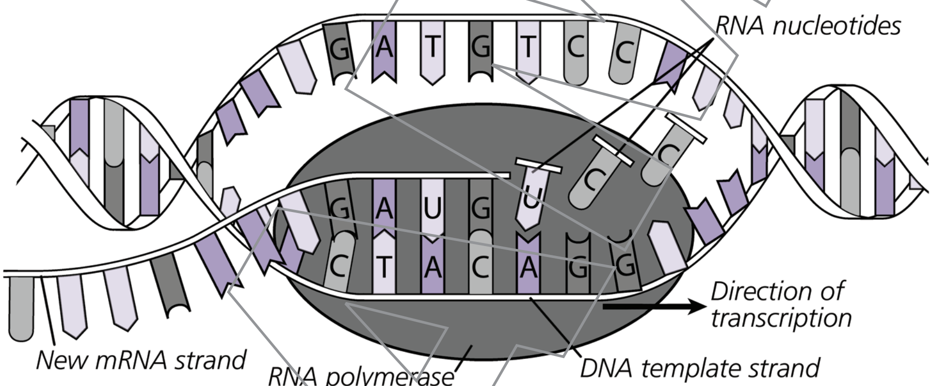
Only one DNA strand will be transcribed into mRNA. This DNA strand is called the *transcribed strand.* Within the nucleus, special proteins called *RNA polymerases* match individual mRNA nucleotides with complementary DNA nucleotides on the transcribed strand. The polymerases bond each mRNA nucleotide to the previous one, building up a strand of mRNA.

In eukaryotes, once an mRNA strand has been transcribed, it is further processed before it exits the nucleus for the cytoplasm.

***Ribonucleic acid,* or *RNA,* is a single-stranded nucleic acid and contains a uracil base (U) in place of the thymine (T) found in DNA.**

Transcription is the process in which genetic information from DNA is copied to mRNA.

Sequences of "junk DNA" may be snipped out of an mRNA transcript by enzymes in the nucleus.



RNA polymerases transcribe DNA into mRNA.

Describe two roles for proteins in the transcription process.

Before an mRNA strand can be constructed, the two strands of a DNA molecule must be separated. Proteins separate the DNA strands. Once the strands are separated, RNA polymerases (which are also proteins) match the mRNA nucleotides to the DNA strand and build the mRNA strand.

Translation: From RNA to Protein

Proteins consist of chains of amino acids, and most proteins contain hundreds of these building blocks. Like the nucleic acids that provide the blueprints, proteins are also made of carbon, hydrogen, and oxygen atoms. Proteins also contain nitrogen and, sometimes, sulfur. There are about 20 different amino acids that make up proteins. The order of amino acids in a protein determines the protein's three-dimensional structure and its function. In turn, the sequence of bases in a strand of mRNA specifies the sequence of amino acids in the protein. This is done in groups of three. Three mRNA bases form a *codon.* A codon is "code" for a particular amino acid. The process of synthesizing proteins from mRNA sequences is called **translation,** as the language of genes is transformed into the language of proteins.

Proteins are synthesized in the cytoplasm of the cell. Translation is carried out by the **ribosomes,** small structures made of rRNA and protein that are found in all cell types. An mRNA strand will bind to a ribosome, which directs the assembly of the amino acid chain.

Ribosomes translate mRNA with the help of another type of RNA called tRNA. The two ends of a tRNA molecule have special functions. One end binds to a free amino acid in the cytoplasm. Each of the 20 different types of amino acids in a cell can be bound by one or more specific tRNA molecules.

The opposite end of a tRNA molecule is a special region called the *anticodon.* The anticodon of tRNA is complementary to a codon on the mRNA transcript. For example, the base sequence UGG is the codon for the amino acid tryptophan. Tryptophan is coded for by the mRNA codon when the tRNA molecule carrying the anticodon, ACC, binds to the mRNA codon, UGG.

A ribosome, mRNA strand, and tRNA molecules work together to assemble a protein. The mRNA strand attaches to a specific site on the ribosome, where the first or "start" codon is exposed. A tRNA molecule with a complementary anticodon binds to the start codon, bringing the first amino acid along with it.

Then, the ribosome moves along the mRNA strand and exposes the next codon, allowing the appropriate tRNA molecule to bring its amino acid into place. As each amino acid is carried to the ribosome, it is bound to the previous amino acid, making the polypeptide chain longer. The tRNA molecule is detached and released into the cytoplasm, the ribosome shifts to the next codon, and the process is repeated.

A protein consists of one or more long chains of amino acids. The chains fold to give it a three-dimensional structure.

Translation is the process in which the base sequence in a strand of mRNA is converted, or "translated," into the amino acid sequence of a protein.

The ribosomes of eukaryotic cells may be found free in the cytoplasm or bound to the rough endoplasmic reticulum. rRNA and protein make up each ribosome.

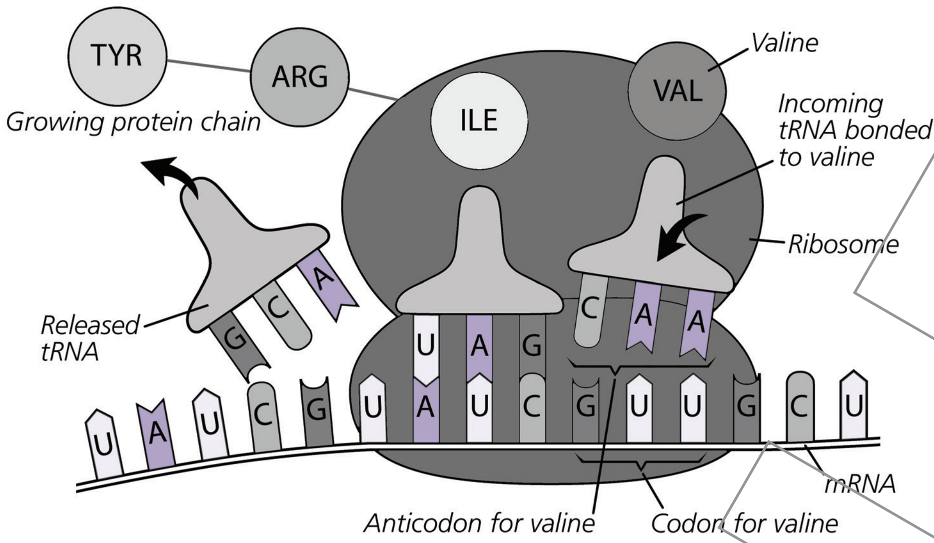
tRNA stands for *transfer RNA,* because it transfers free amino acids to the growing peptide chain on the ribosome.

An *anticodon* is a sequence of three tRNA bases that binds to a complementary mRNA codon.

tRNA and rRNA are also transcribed from genes in the nucleus.

Some amino acids are coded for by more than one codon. For example, histidine is coded for by both CAU and CAC.

A polypeptide is a chain of amino acids, i.e., a protein.



The ribosome and amino-acid–carrying tRNA translate the mRNA sequence into a protein.

The order of amino acids in a protein is only one of the factors that determine the protein's properties. Once the chain has formed, it folds in a specific way, giving it a particular three-dimensional shape. The shape of the protein is very important in allowing it to function properly. Disruption to the shape of a protein can change the protein's function or make it completely nonfunctional.

Special "start" and "stop" codons on mRNA tell the ribosome where translation should begin and end.

The table below contains all amino acids and their associated codons.

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

A strand of DNA contains the following bases: GAT AGA GAT CAA. Transcribe and translate the DNA strand into a sequence of amino acids.

Using the DNA triplets GAT AGA GAT CAA, this would be transcribed to the mRNA codons CUA UCU CUA GUU. Using the genetic code table, these mRNA codons would code for the amino acids leucine, serine, leucine, and valine.

Protein Synthesis in the Cell

The process of transcription of DNA to RNA, followed by the translation of mRNA into protein, is called the *central dogma of molecular biology.* It occurs in all living cells, both prokaryotic and eukaryotic. All cells have polymerase enzymes that transcribe DNA to mRNA and ribosomes that translate the information in mRNA to a sequence of amino acids.

In eukaryotic cells, a number of organelles are also involved in these processes. Chromosomes cannot leave the nucleus, which is where transcription of mRNA occurs. The mRNA strand exits to the cytoplasm through a pore in the nuclear membrane.

In the cytoplasm, ribosomes may be free or bound to the rough endoplasmic reticulum (ER). Proteins that will be used by the cell are translated by the free ribosomes in the cytoplasm. Proteins that are destined for the plasma membrane or for secretion from the cell are assembled by the ribosomes of the rough ER.

The rough ER modifies the newly assembled proteins and packs them into vesicles. These small membrane sacs travel through the cytoplasm to the Golgi apparatus. There, they are further modified so that they reach their intended destinations. From the Golgi apparatus, protein-containing vesicles head toward the plasma membrane of the cell. The flowchart on the next page summarizes the process of protein synthesis in a eukaryotic cell.

The *central dogma of molecular biology* states that information in DNA is transcribed to RNA, which is then translated to protein.

In prokaryotic cells, which lack nuclei, transcription and translation both take place in the cytoplasm.

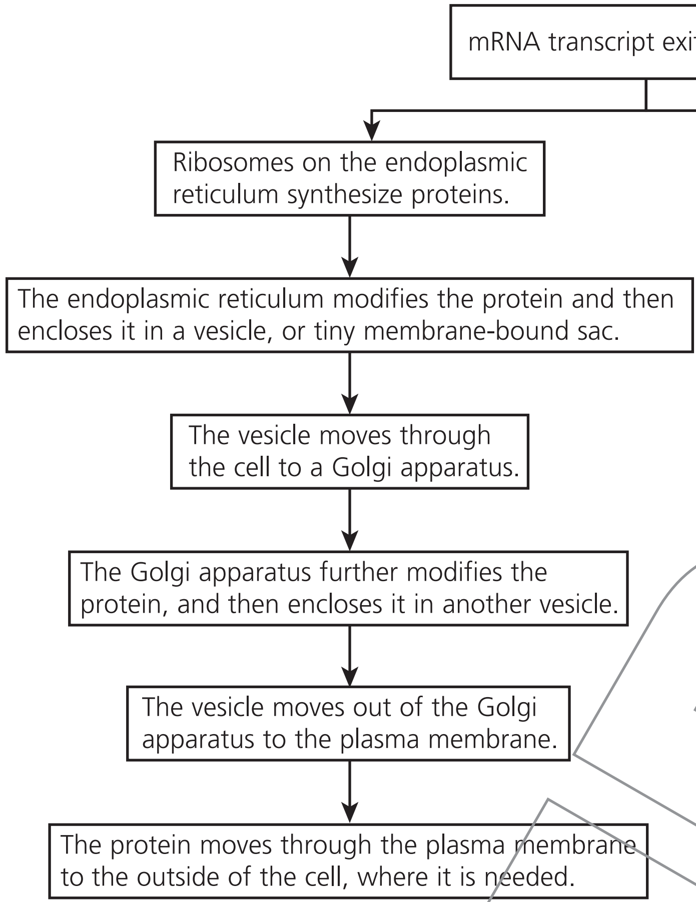
In eukaryotes, ribosomes may be found either free in the cytoplasm or bound to the rough endoplasmic reticulum (ER).

There are two kinds of ER, rough and smooth. Smooth ER is involved in the production of fatty acids and lipids. No ribosomes are attached to smooth ER.

A vesicle is a small membrane sac inside the cell, which may contain material for transport. Proteins are transported in vesicles from the ER to the Golgi apparatus, and then to the plasma membrane.

The Golgi apparatus is an organelle made up of many stacks or folds of membrane. It accepts proteins from the ER, modifies the proteins, packages them into vesicles, and releases the vesicles on the side nearest the plasma membrane.

PROTEIN SYNTHESIS IN EUKARYOTIC CELLS



The fusion of vesicles with the plasma membrane and the release of proteins from the cell is called exocytosis.

Which organelle is not involved in the synthesis and secretion of a protein from the cell?

A ribosome

B smooth ER

C Golgi apparatus

D plasma membrane

Proteins are synthesized by ribosomes of the rough ER and sent to the Golgi apparatus for further modification, so choices A and C are incorrect. From there, the proteins are packaged in vesicles that fuse with the plasma membrane to exit the cell by exocytosis, so choice D is incorrect. The smooth ER, which lacks ribosomes, synthesizes lipids and hormones rather than proteins. Choice B is correct.

It's Your Turn

Please read each question carefully. For a multiple-choice question, circle the letter of the correct response. For a constructed-response question, write your answers on the lines.

1 In which order is a protein created?

A DNA → mRNA → amino acid → protein

B amino acid → mRNA → DNA → protein

C protein → amino acid → mRNA → DNA

D mRNA → protein → DNA → amino acid

Use the table below to answer questions 2 and 3.

MRNA CODONS FOR SEVERAL AMINO ACIDS

Amino Acid	Codons	Amino Acid	Codons
Asparagine	AAU, AAC	Lysine	AAA, AAG
Cysteine	UGU, UGC	Tyrosine	UAU, UAC

2 An mRNA strand codes for the amino acid sequence cysteine-tyrosine-lysine-cysteine-asparagine. Which of the following DNA sequences is used as the template for this mRNA?

A ACA-ATG-TTT-ACG-TTG

B TGT-TAC-AAA-TGC-AAC

C UGU-UAC-AAA-UGC-AAC

D ACA-AUG-UUU-ACG-UUG

3 A tRNA molecule with which of the following anticodons would be able to bind to a molecule of lysine?

A TTT

B TTC

C AAA

D UUC

4 Suppose all of the ribosomes in a cell were destroyed. How would this most likely affect the process of gene expression?

A The DNA double strand would be unable to separate.

B The cell would be unable to form mRNA strands.

C The amino acids could not be joined to form a protein.

D The tRNA molecules would bind to the wrong amino acids.

5 A scientist studying protein synthesis makes the following observations:

A UUU-UUC-CUU-GAA → Protein A

B UUU-UUC-CUA-GAG → Protein A

C UUU-UUC-CUG-GAA → Protein A

Which explanation is supported by the evidence?

A There are multiple DNA codes that can produce the same proteins.

B Each protein is coded for in only one way.

C The sequence of proteins on a chromosome depends upon its genes.

D There are multiple tRNA anticodons that can code for the same protein.

6 A scientist studying DNA and proteins collects the following evidence:

1. Nucleic acids contain A, T, C, G, U.
2. Each amino acid is coded for by a specific sequence of nitrogen bases.
3. Nitrogen bases are essential to the proper assembly of proteins.

A Which conclusion about DNA and proteins can be made from this evidence?

B Describe two differences between transcription and translation.

C Identify one difference between the synthesis of proteins used within the cell and the synthesis of proteins that will be secreted from the cell.