DNA to Proteins

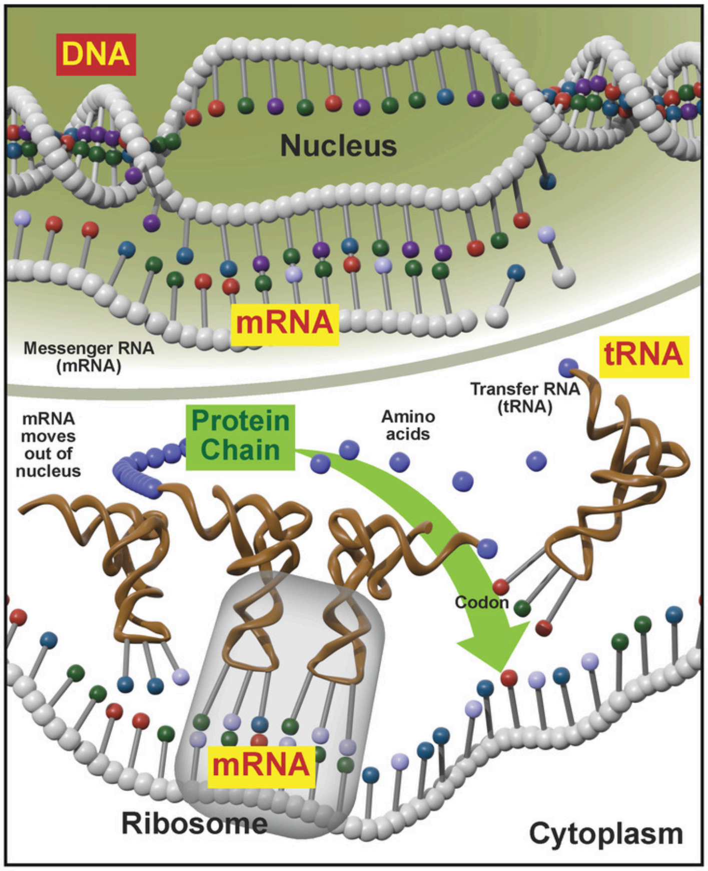
Reflect

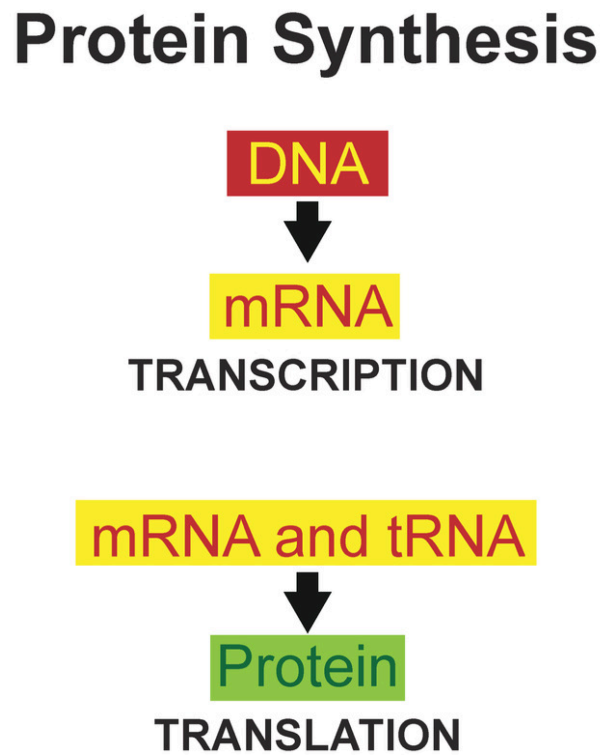
You are probably well aware that your genetic material determines most of your physical **traits**. In a cell, the molecule **deoxyribonucleic acid (DNA)** is the set of “instructions” that controls all aspects of an organism. The combination of DNA inherited from your parents determines all your traits, including your height, hair color, and overall health. How genetic material is inherited is much like being dealt a hand of shuffled cards. There are always the same 52 cards in a deck, but their order may be different depending on how the deck is shuffled. So, how does DNA determine traits? It all has to do with proteins.

What you may not know is that all the healthy cells within an organism contain exact copies of that organism’s genome. A genome is all of an organism’s genetic material, otherwise known as DNA. However, two common questions are often asked. The first is “How is it that DNA controls the traits of living organisms?” The second is “If all the cells in an organism contain the exact same genome, then how can there be different types of cells with different proteins?”

Look Out!

Molecular biology is driven by a central dogma that states that genetic information can flow in only one direction. It flows from DNA to **ribonucleic acid (RNA)** to protein or, in the case of some organisms, just from RNA to proteins. Certain steps are required to decode and transmit the information for each molecule. DNA is replicated and then transcribed into RNA, and then the RNA is translated into amino acid strands that make up a protein. DNA cannot, however, be made from a protein or from RNA. Since the inception of the central dogma by Francis Crick, an exception has been discovered in prions. Prions are infectious proteins that cause a neurological disorder called Creutzfeldt-Jakob disease, which is more commonly known as mad cow disease. These prions are able to replicate without DNA or RNA. These prions are the only known exception to the central dogma.





DNA: Carrier of Protein Instructions

Let us look at the first question: “How is it that DNA controls the traits of living organisms?” The answer involves a very important cellular component. DNA stores all the genetic information required to grow and maintain a living organism. In eukaryotes, DNA may be found in the nucleus of each cell. DNA is a very large molecule known as a biomolecule.

As stated earlier, each cell in an organism contains the entire genome of that organism. If all the DNA within a human cell were laid out in a straight line, it would span approximately two meters in length! To fit inside the tiny cellular nucleus, DNA is folded up tightly. Individual strands are wrapped around special proteins called histones. Histone complexes are then repeatedly coiled to form chromatin. During the prophase of mitosis and meiosis, each strand of chromatin is supercoiled into tightly compact structures called **chromosomes**.

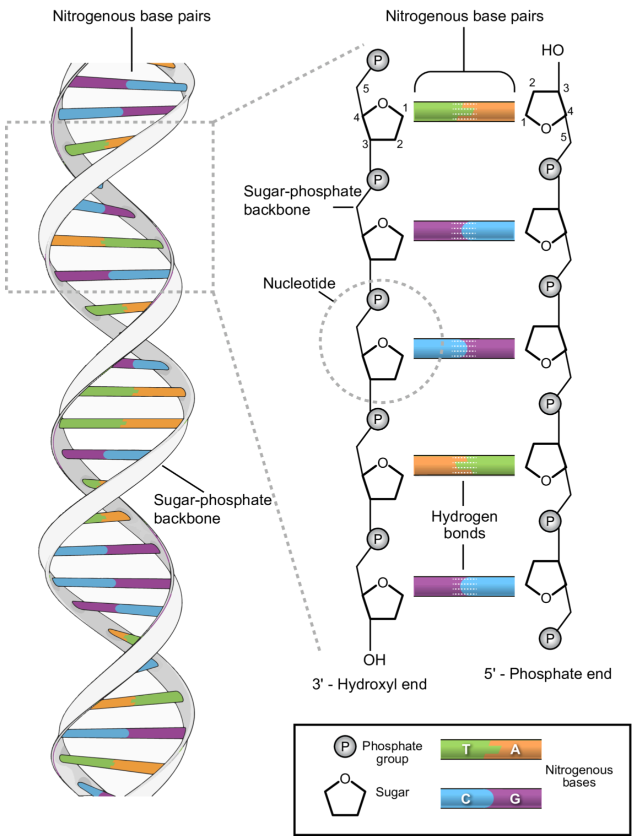
What Do You Think?

How would the world be different if humans could manipulate their genes for a desired trait?

Each chromosome contains one segment of the total component of an organism's DNA. There are noncoding regions of DNA, and scientists are still studying and discovering what the purpose (if any) of these sections may be. But there are also coding regions of DNA known as **genes**, and it is the genes along the chromosomes that determine an organism's traits by specific order of nucleotides.

All biomolecules are also polymers, which means they are made of many repeating units. In the DNA and RNA molecules, these repeating units are called **nucleotides**. A single nucleotide in a DNA molecule contains three chemical groups: a five-carbon sugar, a **phosphate** group, and a **nitrogenous base**. The sugar in DNA is known as deoxyribose. There are four nitrogenous bases: **adenine** (A), **cytosine** (C), **thymine** (T), and **guanine** (G). The identity of each nucleotide is determined by the nitrogenous base attached to it.

As many nucleotides bond, this creates what is known as a sugar-phosphate backbone. The chemical bonds between the sugar and phosphate are very strong chemical bonds. However, the nitrogenous bases of each nucleotide are chemically bonded by weak **hydrogen bonds**. This makes it relatively easy to break these bonds during the processes of **replication** (the process by which DNA makes a copy of itself) and **transcription** (the process of DNA copied into RNA for protein synthesis).



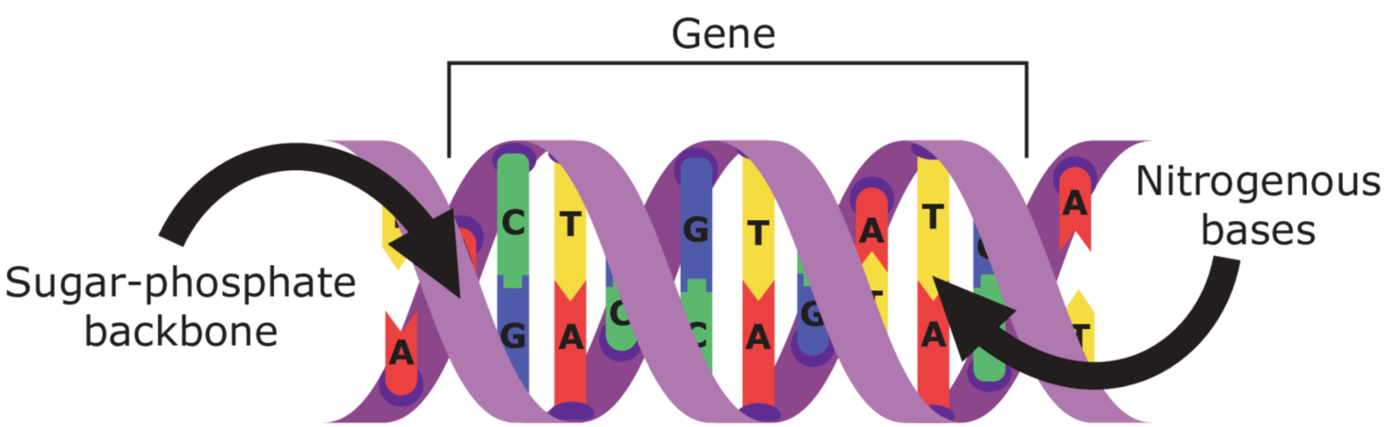
In this way, the DNA molecule may be pictured as similar to a ladder. When looking at DNA, it is easy to see that the sugars and phosphate groups make up the vertical beams of the ladder and the nucleotides make up the horizontal "rungs." To complete the picture, imagine the ladder twisted into a helical configuration. This yields the double helical structure of DNA.

Because of their unique structures, the nitrogenous bases that join two strands of a DNA molecule bind according to the following rules: adenine always binds with thymine, and cytosine always binds with guanine. The two strands of DNA are said to be complementary. Therefore, if the sequence of one strand is known, the other can be found.

Protein Production

The flow of genetic information is DNA → mRNA → protein, according to the central dogma. In this way, DNA specifies what traits will be expressed in an organism. It is the number of nucleotides, as well as the specific nucleotide sequence of all the genes within an organism's DNA, that determines which proteins are created.

Recall that genes are coding sections of DNA that include the sequence necessary to build a protein. A **protein** is a biomolecule, made up of **amino acids**, that folds into a complex structure and has a specific function in an organism. A gene segment of DNA is shown.



During certain portions of the cell cycle, the DNA found in the nucleus of each cell is transcribed into another nucleic acid called **messenger RNA (mRNA)**. This genetic material is important since, unlike DNA, it can travel outside the nucleus to the cytoplasm, where proteins are assembled. The proteins then build certain cell structures that perform specific cellular functions.

The process of reading the information within a cell's DNA to produce a protein takes place in two stages. The first step in protein synthesis is transcription. In this process, mRNA forms a complementary strand to a coding section of DNA (gene). Notice that not all of the DNA is transcribed, only the gene that is needed at this time. The DNA double helix is unzipped or separated, and complementary RNA nucleotides are matched to the DNA sequences. RNA differs from DNA in that it is only a single strand and contains the sugar ribose instead of deoxyribose. Additionally, mRNA lacks the nucleotide thymine (T). In place of thymine, mRNA uses the nucleotide **uracil** (U).

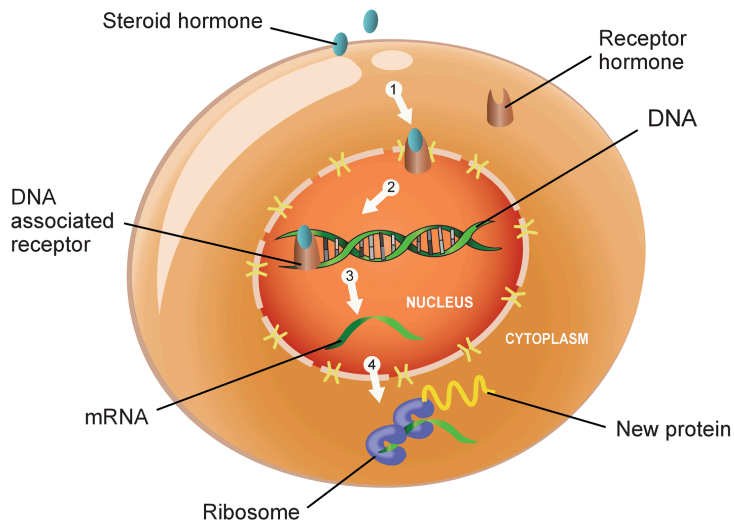
What Do You Think?

Why does RNA use uracil instead of thymine, like DNA?

Uracil is more susceptible to mutation than thymine, and it is also more abundant. Since ribonucleic acid (RNA) is typically transient (made only for short periods of time), uracil's instability doesn't cause problems for the transcription and translation processes but might cause issues in the longer-lived DNA molecule.

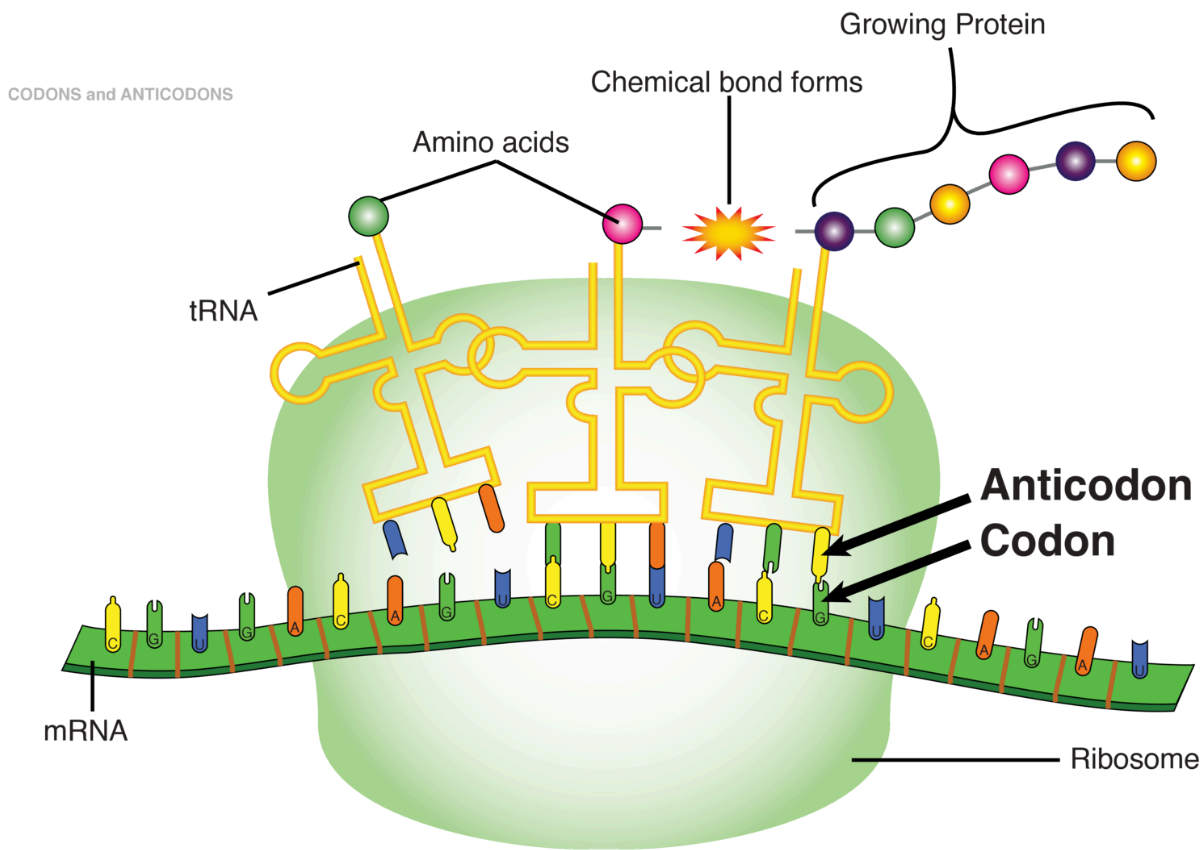
Once the sequence of the DNA is copied into mRNA, the DNA zips back up. The mRNA now contains the DNA "message" and leaves the nucleus. In this way, the DNA stays in the nucleus of the cell and the mRNA can carry the code for the protein out into the cell. Also, most DNA does not code for proteins. Most DNA is not protein-coding, so transcribing only the needed sections (genes) of DNA allows the cell to save energy.

STEROID HORMONES



In the cytoplasm of the cell, the nucleotide code of the mRNA strand is decoded, or translated, into an amino acid code. Amino acids are brought together one by one with the help of other molecules. These amino acids are assembled in the appropriate sequence, or translated, to form the final protein. A **hormone** (a type of protein) can trigger the cell to create another needed protein.

After leaving the nucleus, the mRNA molecule has the genetic code to make a protein. The mRNA is used as a template to produce a protein through a second process called **translation**, or the process of synthesizing proteins from mRNA within an organelle called a **ribosome**. As the mRNA strand moves through the ribosome, it will read three nucleotides at a time. These three-letter sections are called **codons**. Each codon determines which amino acid is added to the polypeptide chain during a process called **protein synthesis**. These codons specify a single amino acid that will be added to a string of amino acids, creating a polymer, which will eventually fold to make a functional protein.



At the ribosome, the RNA's message is translated into a specific protein

Translation begins with the “start” codon, AUG. This codon moves into the ribosome. For every mRNA codon, there is a **transfer RNA (tRNA)** anticodon that base-pairs to the bases of mRNA. Each tRNA molecule can carry only one specific amino acid. The tRNA brings the correct amino acid to the ribosome. The next codon is read. The complementary tRNA base pairs to the codon, bringing the correct amino acid to the ribosome. The ribosome joins the two amino acids together. Another tRNA molecule comes in and reads the next codon. Each amino acid is connected together by peptide bonds to form a protein chain. This process repeats, and the protein will continue growing until a “stop” codon signals the end point for making that particular protein.

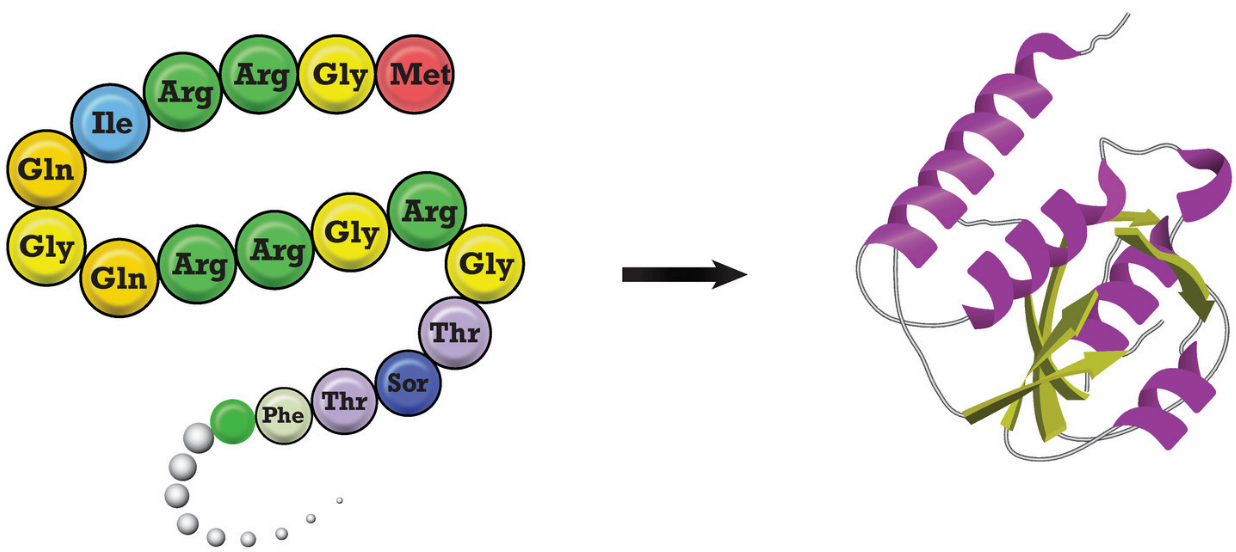
Proteins

As stated earlier, form relates to function, and this is never truer than with proteins. The amino acid chain that is created within the ribosome is not a functional protein. What is produced in the ribosome is simply a chain of amino acids, or a polypeptide chain. Each polypeptide chain produced from the mRNA message in the ribosome may be the information necessary for a single protein, or it may be one part of a larger protein. The polypeptide chain is called the primary structure of a protein.

Once all the polypeptide chains required for a specific protein are created, these chains will then fold to create a functional protein. The secondary structures of proteins contain areas known as alpha-helices and beta-pleated sheets. These areas are chemically bonded by hydrogen bonds that form between specific chemical components of the amino acids. These chemical bonds then create molecular structures, based on which components are bonded. Human insulin, for instance, consists of two peptide chains.

After all the chemical bonds have been created, each single polypeptide chain will be folded into its functional structure, also called the tertiary structure. If a protein requires more than one polypeptide chain, it will fold these chains together into a quaternary structure. Both tertiary and quaternary structures make up the three-dimensional molecules that are known as functional proteins. All molecules prefer to be in their lowest energy state. This means that the final form of the functional protein molecule is shaped in such a way as to be in the lowest energy state. The quaternary structure of a protein is shown.

Polypeptide Chain Fold into Active Protein



Specialized Cells

Specialized cells use very specific proteins to carry out all essential life functions. This is true for all organisms but especially for complex multicellular organisms. Cells can turn the genes that make proteins “on” and “off” as needed. This ability to control which genes are used or needed is known as **gene expression**. Gene expression also allows for the creation of specialized cells, as even the slightest difference in an organism’s DNA can have a major effect on how a gene is expressed.

Complex eukaryotes, such as vascular plants and most animals, contain a wide variety of cell types. For example, think about the differences between muscle cells, brain cells, and blood cells. Each of these cell types has a different structure and performs a different job. In plants, root cells absorb water and minerals from the soil. Specialized cells in the leaf must allow for photosynthesis, for the intake of carbon dioxide, and for the release of oxygen gas. Other cells in the plant provide structure for stems and leaves or create tissues that carry water and nutrients throughout the plant. These examples show that differentiated cells perform different functions, so these cells express different genes.

Enzymes

There are many types of proteins. Almost all **enzymes** are composed of amino acid chains. This means that enzymes are one type or category of proteins that catalyze chemical reactions within biological organisms. This makes enzymes biological **catalysts**, as they accelerate chemical reactions within the cells of living organisms. There are thousands of enzymes used in life processes, including respiration, cell growth, and digestion.

Proteins determine virtually everything about a living cell and, thus, an entire organism. Proteins determine factors such as the cell's structure and its function. Proteins regulate which materials will be transported into and out of cells. They also determine the products a cell might make. Simply put, the DNA of our genome controls cellular fate by providing the instructions for making each and every protein within a cell. The proteins that are created through transcription and translation may be used as structural proteins, as enzymes to catalyze specific chemical reactions, or as chemical messages to communicate with other cells. Some proteins need to be made early in the life of a cell, while other proteins are needed as it grows and matures. Most proteins are needed for organisms to function throughout their lives, making the proteins essential biomolecules for all living organisms.

Try Now

Reviewing Key Terms

1. Use each of the following terms in a separate sentence.

   A. Central dogma

   B. DNA

   C. Gene

   D. Genome

   E. Protein

   F. Enzyme

2. Use the correct key term to complete each of the following sentences.

   A. Coding regions of the DNA found in chromosomes are known as ________________.

   B. Long chains of amino acids that determine virtually everything about a cell, including cell structure and function, cell material regulation, and cell products are called ____.

   C. ___________________________ are specialized proteins that trigger the making of other proteins.

Reviewing Main Ideas

1. Which statement is true regarding genes and DNA?
    A. Each DNA strand contains identical genes.
    B. The DNA transcribes only the genes it needs at specific times.
    C. DNA and genes are the same length.
    D. Genes are the coding regions of DNA.
2. What portion of the DNA is also known as a gene?
    A. The coding section
    B. The noncoding section
    C. The mRNA strand
    D. The polypeptide sequence
3. What does the codon sequence on the mRNA strand determine?
    A. The gene sequence of the DNA
    B. The amino acid sequence of the polypeptide
    C. The codon that is signaled
    D. The signaling sequence
4. Which of the following is NOT true about proteins?
    A. Proteins are found only within the cells of organisms.
    B. Proteins within a cell determine factors such as the cell's structure and its function.
    C. Proteins regulate which materials will be transported into and out of cells.
    D. Proteins determine the products a cell might make.

Making Connections

1. What is the purpose of transcription?

2. What are genes, where are they found, and what do they do?

3. In your own words, explain the central dogma of molecular biology and how DNA, RNA, and proteins are connected.

Open-Ended Response

1. Explain the relationship between amino acids, proteins, and DNA.

2. In your own words, explain the process of translating mRNA into a polypeptide sequence. Use the following terms: *mRNA*, *amino acid*, *polypeptide*, *ribosome*, *tRNA*, and *codon*.

DNA to Proteins

Connecting With Your Child

The discovery of a particular category of enzymes, known as restriction enzymes, has revolutionized the field of genetics. Restriction enzymes catalyze reactions that involve breaking apart strands of DNA at specific nucleotide sequences. This type of enzyme has been used to cut apart fragments of human DNA to learn about small differences in the DNA sequences between individual people. Restriction enzymes have also allowed the development of genetic engineering.

Restriction enzymes were first discovered in bacteria. Scientists think that these enzymes evolved as a way for bacteria to cut apart viral DNA, thus defending against invading viruses. There are many different restriction enzymes, each of which snips apart DNA at a unique nucleotide sequence.

Use a variety of internet resources to learn more about restriction enzymes and how they are revolutionizing the field of genetics. Make sure to research how these enzymes were discovered, what types of enzymes are included in this category, and what each type of restriction enzyme does. Also include how scientists plan to use them in the study of genetics, as well as any possible ethical dilemmas scientists face.

Create a multimedia presentation to illustrate restriction enzymes, their discovery, their usefulness, and how they may change the field of genetics. Your presentation should include at least 10 slides. Make sure to include valid evidence supporting your research.