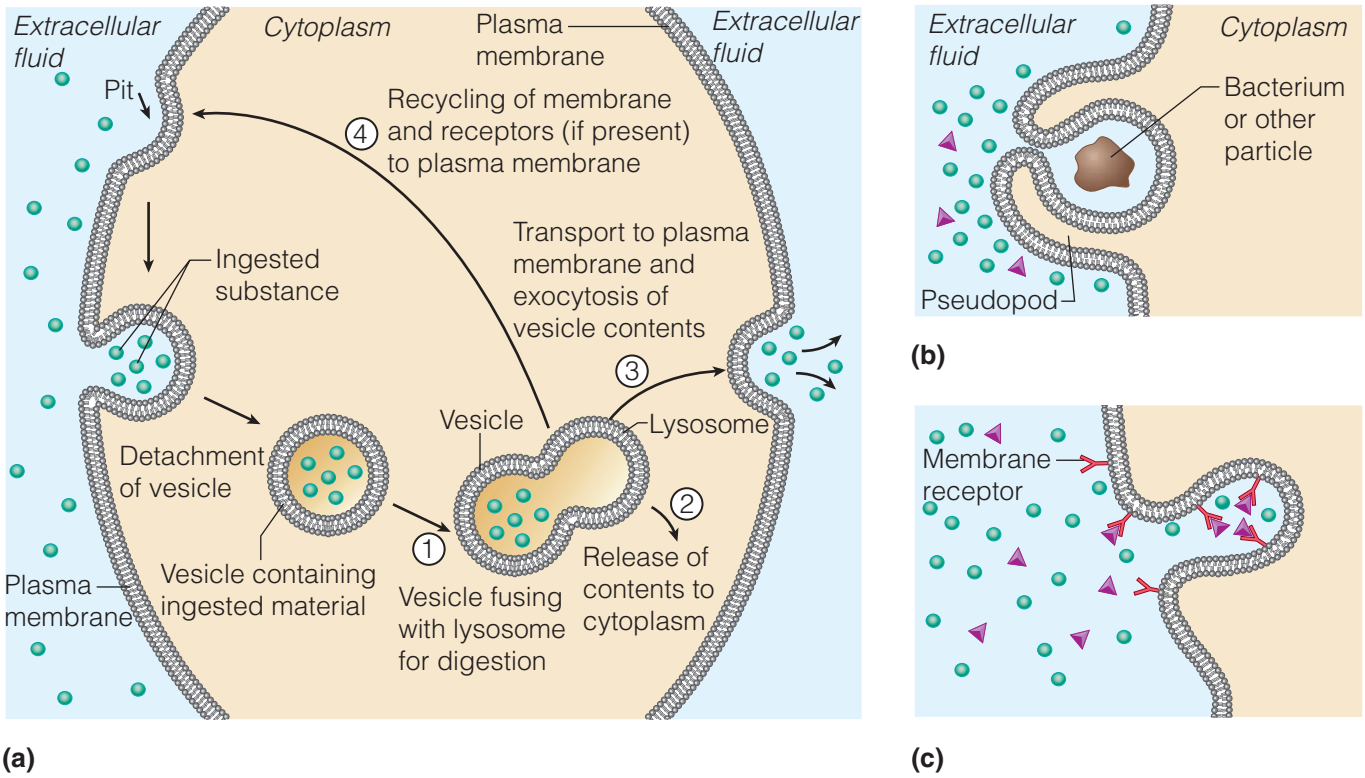

FIGURE 3.13 **Events and types of endocytosis. (a)** Sequence of events in endocytosis. Once the vesicle has detached from the plasma membrane its contents may be digested within a lysosome and then released to the cytoplasm (its membrane components, and receptors if present, are recycled to the plasma membrane); or the vesicle may be transported across the cell intact and then released to the cell exterior by exocytosis. The type illustrated is pinocytosis, also called fluid-phase endocytosis. **(b)** Phagocytosis. **(c)** Receptor-mediated endocytosis.

Cell Division

The **cell life cycle** is the series of changes a cell goes through from the time it is formed until it divides. The cycle has two major periods: **interphase,** in which the cell grows and carries on its usual metabolic activities, and **cell division,** during which it reproduces itself. Although the term *interphase* leads one to believe that it is merely a resting time between the phases of cell division, this is not the case. During interphase, which is by far the longer phase of the cell cycle, the cell is very active and is resting *only* from division. A more accurate name for interphase would be *metabolic phase.*

Preparations: DNA Replication

The function of cell division is to produce more cells for growth and repair processes. Because it is essential that all body cells have the same genetic material, an important event *always precedes* cell division: the genetic material (the DNA molecules that form part of the chromatin) is duplicated exactly. This occurs toward the end of the cell's interphase period.

You will recall from Chapter 2 that DNA is a very complex molecule. It is composed of building blocks called *nucleotides,* each consisting of deoxyribose sugar, a phosphate group, and a nitrogen-containing base. Essentially DNA is a *double helix,* a ladderlike molecule that is coiled into a spiral staircase shape. The upright parts of the DNA "ladder" are alternating phosphate and sugar units, and the rungs of the ladder are made of pairs of nitrogen-containing bases.

The precise trigger for DNA synthesis is unknown, but once it starts, it continues until all the DNA has been replicated. The process begins as the DNA helix uncoils and gradually separates into

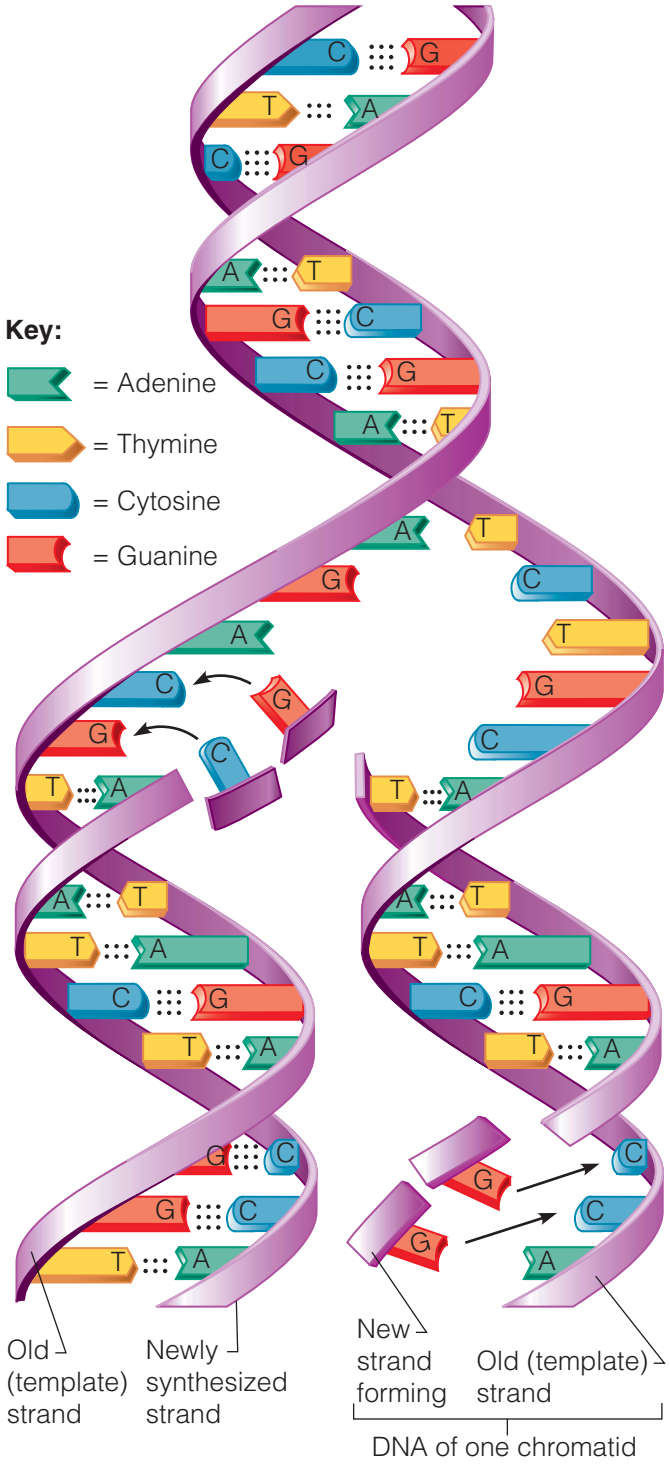

FIGURE 3.14 Replication of the DNA molecule during interphase. The DNA helix unwinds (center), and its nucleotide strands are separated. Each strand then acts as a template for building a new complementary strand. As a result, two helixes, each identical to the original DNA helix, are formed.

its two nucleotide chains (Figure 3.14). Each nucleotide strand then serves as a *template,* or set of instructions, for building a new nucleotide strand.

Remember that nucleotides join in a *complementary* way: adenine (A) always bonds to thymine (T), and guanine (G) always bonds to cytosine (C). Hence, the order of the nucleotides on the template strand also determines the order on the new strand. For example, a TACTGC sequence on a template strand would bond to new nucleotides with the order ATGACG. The end result is that two DNA molecules are formed that are identical to the original DNA helix, and each consists of one old and one newly assembled nucleotide strand.

Events of Cell Division

In all cells other than bacteria and some cells of the reproductive system, cell division consists of two events. **Mitosis** (mi-to″sis), or division of the nucleus, occurs first. The second event is division of the cytoplasm, **cytokinesis** (si′to-kĭ-ne″sis), which begins when mitosis is nearly completed.

Mitosis Mitosis results in the formation of two daughter nuclei with exactly the same genes as the mother nucleus. As explained above, DNA replication precedes mitosis, so that for a short time the cell nucleus contains a double dose of genes. When the nucleus divides, each *daughter cell* ends up with *exactly* the same genetic information as the original mother cell and the original fertilized egg from which it came.

The stages of mitosis, diagrammed in Figure 3.15, include the following events:

- **Prophase** (pro′faz). As cell division begins, the chromatin threads coil and shorten so that visible barlike bodies called **chromosomes** (*chromo* = colored; *soma* = body) appear. Because DNA replication has already occurred, each chromosome is actually made up of two strands, each called a **chromatid** (kro′mah-tid), held together by a small buttonlike body called a **centromere** (sen′tro-mer). The centrioles separate from each other and begin to move toward opposite sides of the cell, directing the assembly of a **mitotic spindle** (composed of thin microtubules) between them as they move. The spindle provides a scaffolding for the attachment and movement of the chromosomes during the later mitotic stages. By the end of prophase, the nuclear envelope and the nucleoli have broken down and disappeared,

Q *When in the cell cycle is each chromosome made up of two chromatids?*

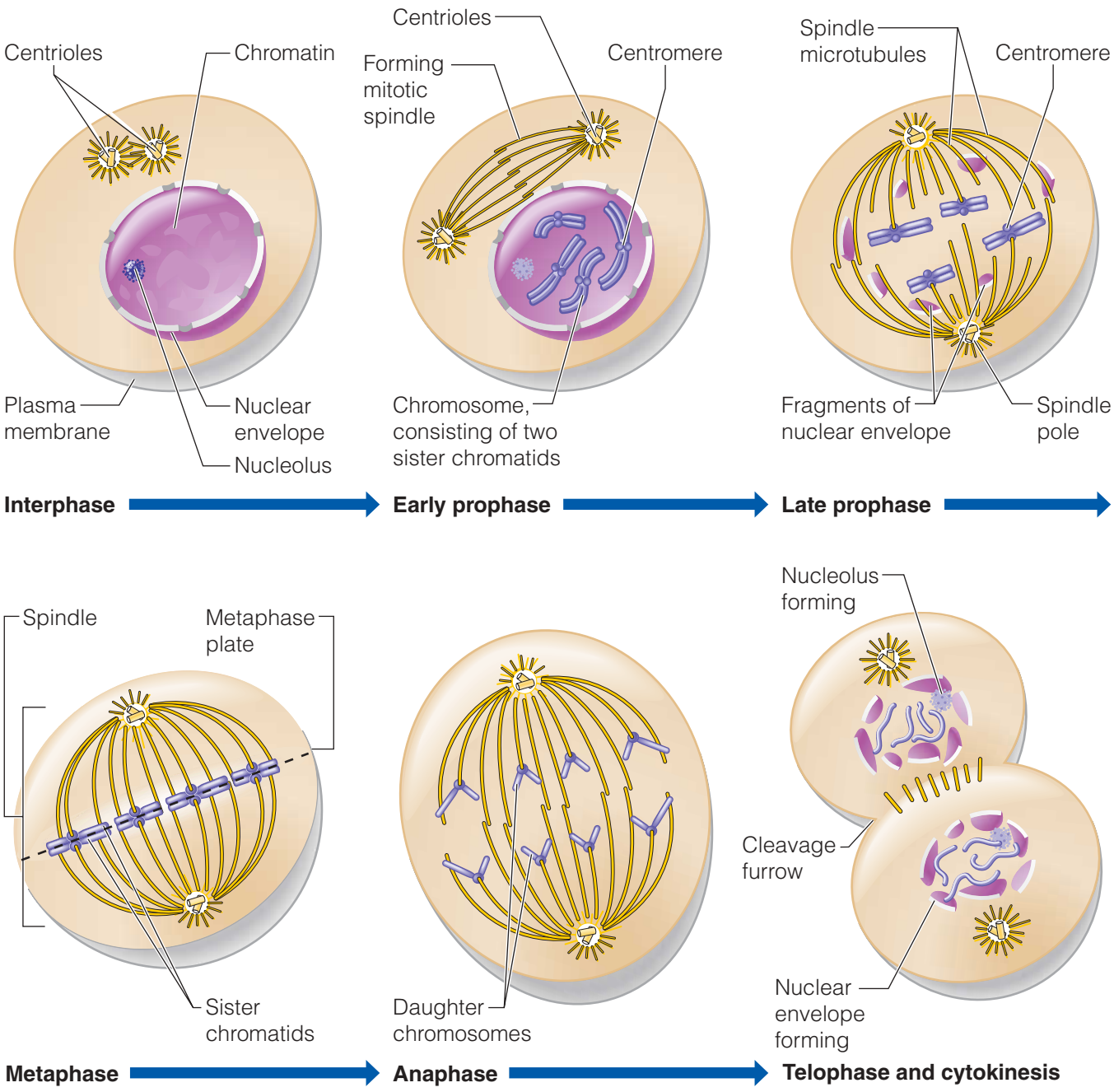

FIGURE 3.15 **Stages of mitosis.**

and the chromosomes have attached randomly to the spindle fibers by their centromeres.

- **Metaphase** (met′ah-faz). In this short stage, the chromosomes cluster and become aligned at the *metaphase plate* (the center of the spindle midway between the centrioles) so that a straight line of chromosomes is seen.
- **Anaphase** (an′ah-faz). During anaphase, the centromeres that have held the chromatids together split. The chromatids (now called chromosomes again) begin to move slowly

A *From the end of interphase to early anaphase.*

apart, drawn toward opposite ends of the cell. The chromosomes seem to be pulled by their half-centromeres, with their "arms" dangling behind them. Anaphase is over when chromosome movement ends.

- **Telophase** (tel′o-faz). Telophase is essentially prophase in reverse. The chromosomes at opposite ends of the cell uncoil to become threadlike chromatin again. The spindle breaks down and disappears, a nuclear envelope forms around each chromatin mass, and nucleoli appear in each of the daughter nuclei.

Mitosis is basically the same in all animal cells. Depending on the type of tissue, it takes from 5 minutes to several hours to complete, but typically it lasts about 2 hours. Centriole replication is deferred until late interphase of the next cell cycle, when DNA replication begins before the onset of mitosis.

Cytokinesis Cytokinesis, or the division of the cytoplasm, usually begins during late anaphase and completes during telophase. Due to the activity of a contractile ring made of microfilaments, a **cleavage furrow** appears over the midline of the spindle, and it eventually squeezes or pinches the original cytoplasmic mass into two parts. Thus, at the end of cell division, two daughter cells exist. Each is smaller and has less cytoplasm than the mother cell, but it is genetically identical to it. The daughter cells grow and carry out normal cell activities until it is their turn to divide.

Although mitosis and division of the cytoplasm usually go hand in hand, in some cases the cytoplasm is not divided. This condition leads to the formation of *binucleate* (two nuclei) or *multinucleate* cells. This is fairly common in the liver.

As mentioned earlier, mitosis provides the "new" cells for body growth in youth and is necessary to repair body tissue all through life. Mitosis gone wild is the basis for tumors and cancers.

Protein Synthesis

Genes: The Blueprint for Protein Structure

In addition to replicating itself for cell division, DNA serves as the master blueprint for protein syntheses. Traditionally, a **gene** is defined as a DNA segment that carries the information for building one protein or polypeptide chain.

Proteins are key substances for all aspects of cell life. As described in Chapter 2, *fibrous (structural) proteins* are the major building materials for cells. Other proteins, the *globular (functional) proteins,* do things other than build structures. For example, all **enzymes,** biological catalysts that regulate chemical reactions in the cells, are functional proteins. The importance of enzymes cannot be overstated. Every chemical reaction that goes on in the body requires an enzyme. It follows that DNA regulates cell activities largely by specifying the structure of enzymes, which in turn control or direct the chemical reactions in which carbohydrates, fats, other proteins, and even DNA itself are made and broken down.

How does DNA bring about its miracles? It appears that DNA's information is encoded in the sequence of bases along each side of the ladder-like DNA molecules. Each sequence of *three* bases (a *triplet*) calls for a particular *amino acid* (Figure 3.16). (Amino acids are the building blocks of proteins that are joined during protein synthesis.) For example, a DNA base sequence of AAA specifies an amino acid called phenylalanine, while CCT calls for glycine. Just as different arrangements of notes on sheet music are played as different melodies, variations in the arrangements of A, C, T, and G in each gene allow cells to make all the different kinds of proteins needed. It has been estimated that a single gene has between 300 and 3000 base pairs in sequence.

The Role of RNA

By itself, DNA is rather like a strip of magnetic recording tape; its information is not useful until it is decoded. Furthermore, most ribosomes—the manufacturing sites for proteins—are in the cytoplasm, but in interphase cells DNA never leaves the nucleus. Thus, DNA requires not only a decoder but also a messenger to achieve its task of specifying the structure of proteins to be built at the ribosomes. These messenger and decoder functions are carried out by the second type of nucleic acid, called **ribonucleic** (ri″bo-nu-kle′ik) **acid,** or **RNA.**

As you learned in Chapter 2, RNA differs from DNA in being single-stranded and in having ribose sugar instead of deoxyribose and a uracil (U) base instead of thymine (T). Three varieties of RNA play a special role in protein synthesis. **Transfer RNA (tRNA) molecules** are small cloverleaf-shaped

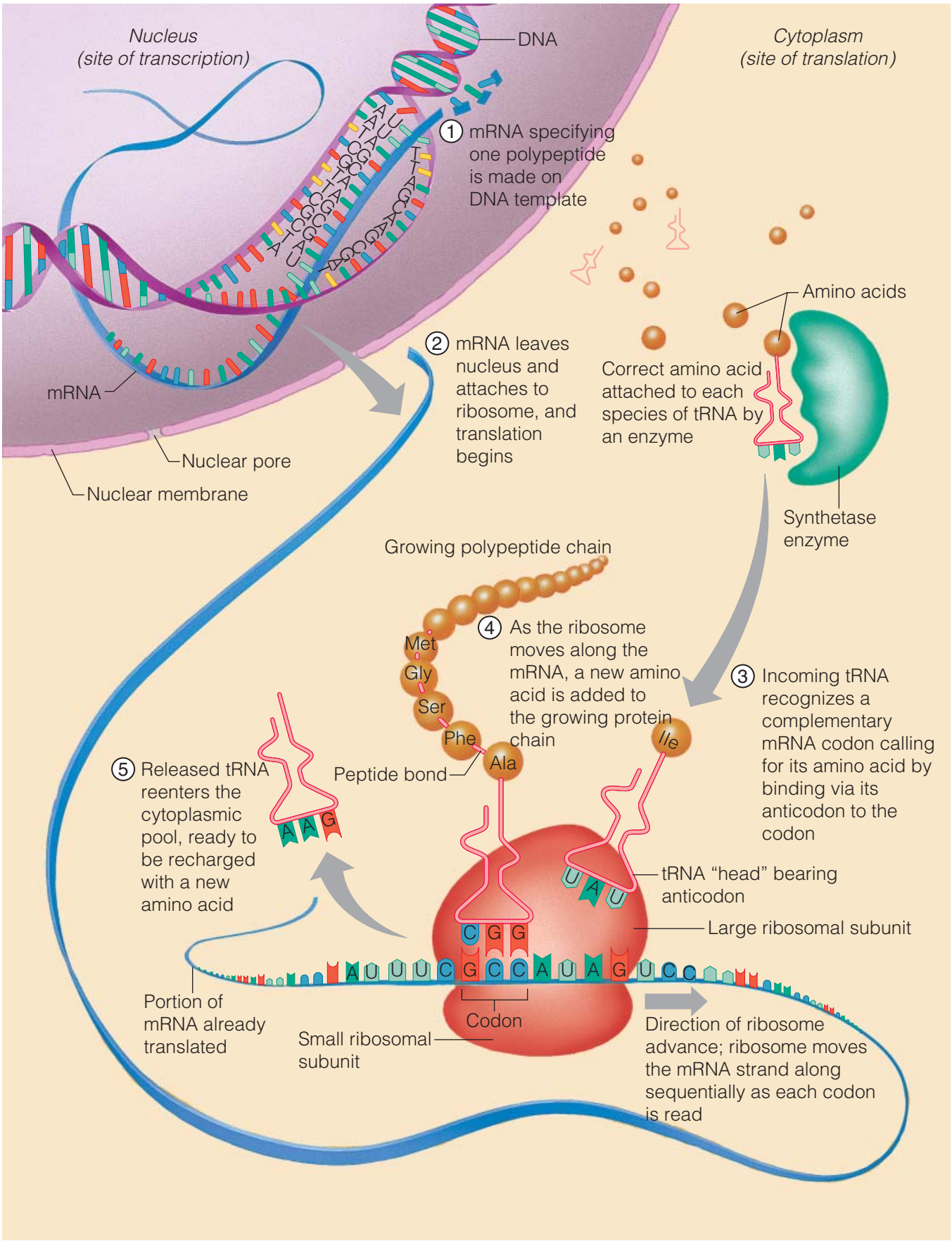

FIGURE 3.16 **Protein synthesis.** (①) Transcription. (②–⑤) Translation.

molecules. **Ribosomal RNA (rRNA)** helps form the ribosomes, where proteins are built. **Messenger RNA (mRNA) molecules** are long, single nucleotide strands that resemble half of a DNA molecule and carry the "message" containing instructions for protein synthesis from the DNA gene in the nucleus to the ribosomes in the cytoplasm.

Protein synthesis involves two major phases: *transcription,* when complementary mRNA is made at the DNA gene, and *translation,* when the information carried in mRNA molecules is "decoded" and used to assemble proteins. These steps are summarized simply in Figure 3.16, and described in more detail next.

Transcription

The word *transcription* often refers to one of the jobs done by a secretary—converting notes from one form (shorthand notes or an audiotape recording) into another form (a typewritten letter, for example). In other words, the same information is transformed from one form or format to another. In cells, **transcription** involves the transfer of information from DNA's base sequence into the *complementary* base sequence of mRNA (Figure 3.16, step 1). Only DNA and mRNA are involved in transcription. Whereas each three-base sequence specifying a particular amino acid on the DNA gene is called a **triplet,** the corresponding three-base sequences on mRNA are called **codons.** The form is different, but the same information is being conveyed. Thus, if the (partial) sequence of DNA triplets is AAT-CGT-TCG, the related codons on mRNA would be UUA-GCA-AGC.

Translation

A translator takes words in one language and restates them in another language. In the **translation phase** of protein synthesis, the language of nucleic acids (base sequence) is "translated" into the language of proteins (amino acid sequence). Translation occurs in the cytoplasm and involves three major varieties of RNA. As illustrated in Figure 3.16, steps 2–5, translation consists of the following events. Once the mRNA attaches to the ribosome (step 2), tRNA comes into the picture. Its job is to transfer, or ferry, amino acids to the ribosome, where they are bound together by enzymes in the exact sequence specified by the gene (and its mRNA). There are about 45 common types of tRNAs, each capable of carrying one of the 20 or so common types of amino acid to the protein synthesis sites. But that is not the only job of the tiny tRNAs. They also have to recognize the mRNA codons "calling for" the amino acid they are toting. They can do this because they have a special three-base sequence called an **anticodon** on their "head" that can bind to the complementary codons (step 3).

Once the first tRNA has maneuvered itself into the correct position at the beginning of the mRNA message, the ribosome moves the mRNA strand along, bringing the next codon into position to be read by another tRNA. As amino acids are brought to their proper positions along the length of mRNA, they are joined together by enzymes (step 4). As an amino acid is bonded to the chain, its tRNA is released and moves away from the ribosome to pick up another amino acid (step 5). When the last codon (the termination, or "stop," codon) is read, the protein is released.

PART II: BODY TISSUES

The human body, complex as it is, starts out as a single cell, the fertilized egg, which divides almost endlessly. The millions of cells that result become specialized for particular functions. Some become muscle cells, others the transparent lens of the eye, still others skin cells, and so on. Thus, there is a division of labor in the body, with certain groups of highly specialized cells performing functions that benefit the organism as a whole.

Cell specialization carries with it certain hazards. When a small group of cells is indispensable, its loss can disable or even destroy the body. For example, the action of the heart depends on a very specialized cell group in the heart muscle that controls its contractions. If those particular cells are damaged or stop functioning, the heart will no longer work efficiently, and the whole body will suffer or die from lack of oxygen.

Groups of cells that are similar in structure and function are called **tissues.** The four primary tissue types—epithelium, connective tissue, nervous tissue, and muscle—interweave to form the fabric of the body. If we had to assign a single term to each primary tissue type that would best describe its overall role, the terms would most likely be *covering* (epithelium), *support* (connective), *movement* (muscle), and *control* (nervous). However,