8.4: Ribonucleic acid (RNA) and transcription

Learning Objectives

- Understand the basic structural features and functions of RNAs involved in protein synthesis, including mRNA, tRNA, and rRNA.
- Understand the transcription process, i.e., synthesis of mRNA from the DNA template, codons on DNA and mRNA, and anticodons on tRNA that specify amino acid to be incorporated in the protein.

Ribonucleic acid (RNA)

Ribonucleic acid (RNA) is a type of nucleic acid present in all cell types. It is structurally similar to DNA, as shown in Figure 8.4.1, but differs from it concerning the following.

1. RNA is often single-stranded.
2. The backbone of RNA is made of ribose units (rather than deoxyribose in DNA) connected by phosphodiester linkages.
3. Three nitrogen bases in RNA, i.e., adenine (A), Guanine (G), and cytosine (C), are the same as in DNA, but the fourth one is uracil (U) in RNA in the place of thymine (T) in DNA.

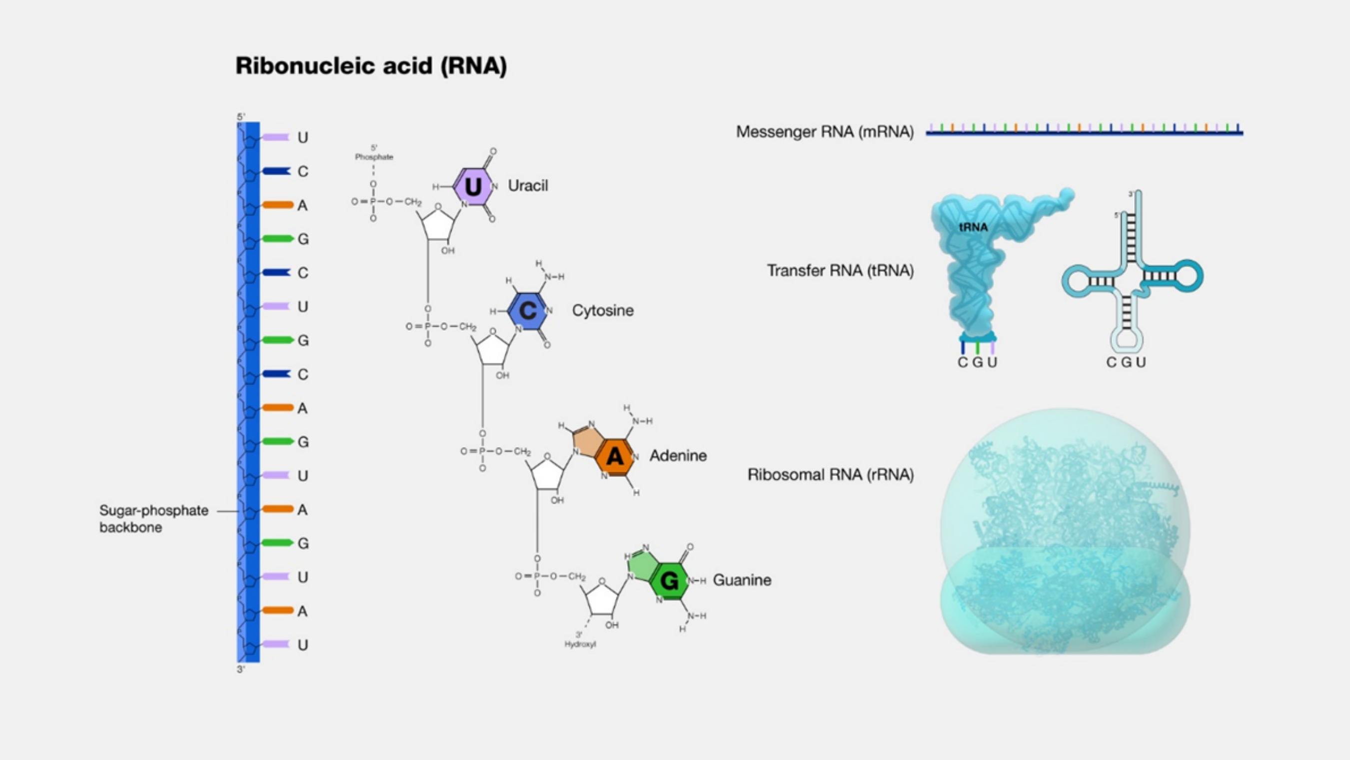


Figure 8.4.1: Illustration of a single-stranded ribonucleic acid (RNA) showing alternating phosphate-ribose backbone with nitrogen bases hanging out from ribose (left), the skeletal structure of a portion of an RNA (middle), and three types of RNA's involved in protein synthesis, i.e., messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA) (right). (Copyright; National Human Genome Research Institute, Public domain)

Types of RNAs Involved in protein synthesis

Three types of RNA are involved in protein synthesis, i.e., messenger RNA (mRNA), transfer RNA (tRNA), and ribosomal RNA (rRNA), as illustrated in Figure 8.4.1. Some other RNAs have functions other than protein synthesis. Some viruses use RNA as genetic material rather than DNA.

Messenger RNA (mRNA)

Messenger RNA (mRNA) is a single-stranded RNAs as illustrated in Figure 8.4.1. It is synthesized as a complementary strand of a section of one of the two strands of DNA that carry information for synthesizing a protein cell needs. The message RNA is synthesized in the nucleus and travels to the cytoplasm (watery interior of the cell outside the nucleus), where protein-synthesis machinery, i.e., ribosomes, reads the information and synthesizes the protein.

Transfer RNA (tRNA)

The transfer RNA (tRNA) is a small RNA comprising 70 to 90 nucleotides. Its job is to bring an amino acid to the protein synthesis location and incorporate it at a specific place in the protein, dictated by the codons on the mRNA. Hydrogen bonding in some complimentary bases in the tRNA makes it fold, producing loops and double-stranded portions, as illustrated in Figure 8.4.2. The 3D shape of the tRNA is twisted, appearing like L-shape, but it is usually depicted as a cloverleaf-like shape in 2D presentation. The loops include a D loop, a T loop, an anticodon loop, a variable loop that is a slight bulge between the T loop and the anticodon loop, and a receptor stem that contains the 3' end and 5' end of the tRNA molecule. The anticodon makes the tRNA specific for one amino acid. The anticodon is complementary to the codon on the mRNA.

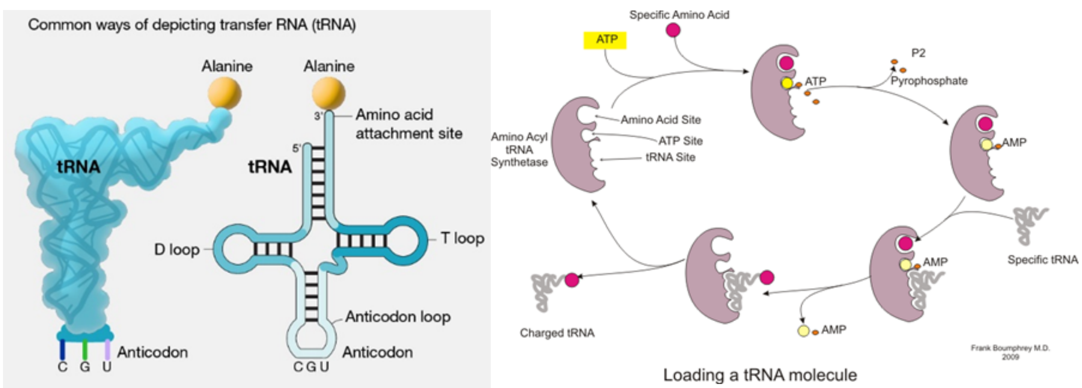
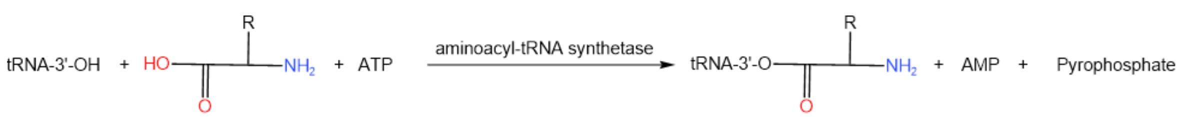


Figure 8.4.2: A 3D structure of a tRNA that is specific for amino acid alanine, its 2D depiction (left), and attachment of an amino acid to the free 3' $-\mathrm{OH}$ group of tRNA through an ester linkage using the energy released by ATP and catalyzed by enzyme aminoacyl tRNA synthetase (right). (Copyright; left: National Human Genome Research Institute, Public domain, right: Boumphreyfr, CC BY-SA 3.0, via Wikimedia Commons)

Activation of tRNA

Attaching an amino acid to tRNA is called activation of tRNA. The 3' end of tRNA always has adenosine (A) followed by two cytosines (C), i.e., ACC sequence. The free 3' $-\mathrm{OH}$ group of adenosine nucleotide makes an ester bond with an amino acid through the following reaction.



Anticodon

There is a different amino acyl-tRNA synthetase for each of the tRNA. Each tRNA is specific for one of the 20 amino acids. The particular shape of tRNA dictates this specificity. The tRNA and the amino acid corresponding to it fit in the active site of the corresponding amino acyl-tRNA synthetase, as illustrated in Figure 8.4.2. Each tRNA has a separate anticodon, a sequence of three nucleotides complementary to the corresponding codon on the mRNA, i.e., A pairs with U, G pairs with C, and vice versa. For example, mRNA codon GCA is complementary to the anticodon UGC on a tRNA shown in Figure 8.4.2 that specifies amino acid alanine in the protein.

Ribosomal RNA (rRNA)

Ribosomal RNA (rRNA) is the most abundant type of RNA that combines with proteins and makes ribosomes. Ribosome has two subunits, a large subunit, and a small subunit, as illustrated in Figure 8.4.1. Ribosome is the site for protein synthesis. There are many ribosomes in the cells.

Transcription

Gene is a section of DNA that is a basic unit of heredity passed from parent to child. Gene is a sequence of nucleotides in the DNA that encodes information for making specific proteins that lead to the expression of a particular physical character or trait, such as hair color or eye color, or some other specific function in the cell. Humans have about 20,000 protein-coding genes. Some genes encode the synthesis of RNAs that have functions other than protein synthesis.

Transcription is the process of mRNA synthesis using a protein synthesis gene portion of a DNA strand as a template, as illustrated in Figure 8.4.3.

The process begins when the gene portion of the DNA unwinds, and RNA polymerase catalyzes mRNA synthesis from a 3' to 5' direction, using a strand of the unwound DNA going from a 5' to 3' direction as a template. The unwound gene portion of the DNA is called the **transcription bubble**. The process stops when the RNA polymerase reaches the sequence of nucleotides on the template DNA that is a stop single. The mRNA is released from the DNA, and the unwound portion of the DNA returns to its regular double helix structure. The mRNA is processed further in the nucleus. Then it leaves from the nucleus to the cytoplasm (watery interior of the cell outside the nucleus), where protein-synthesis machinery, i.e., ribosomes, reads the information and synthesizes the protein in a process called **translation**.

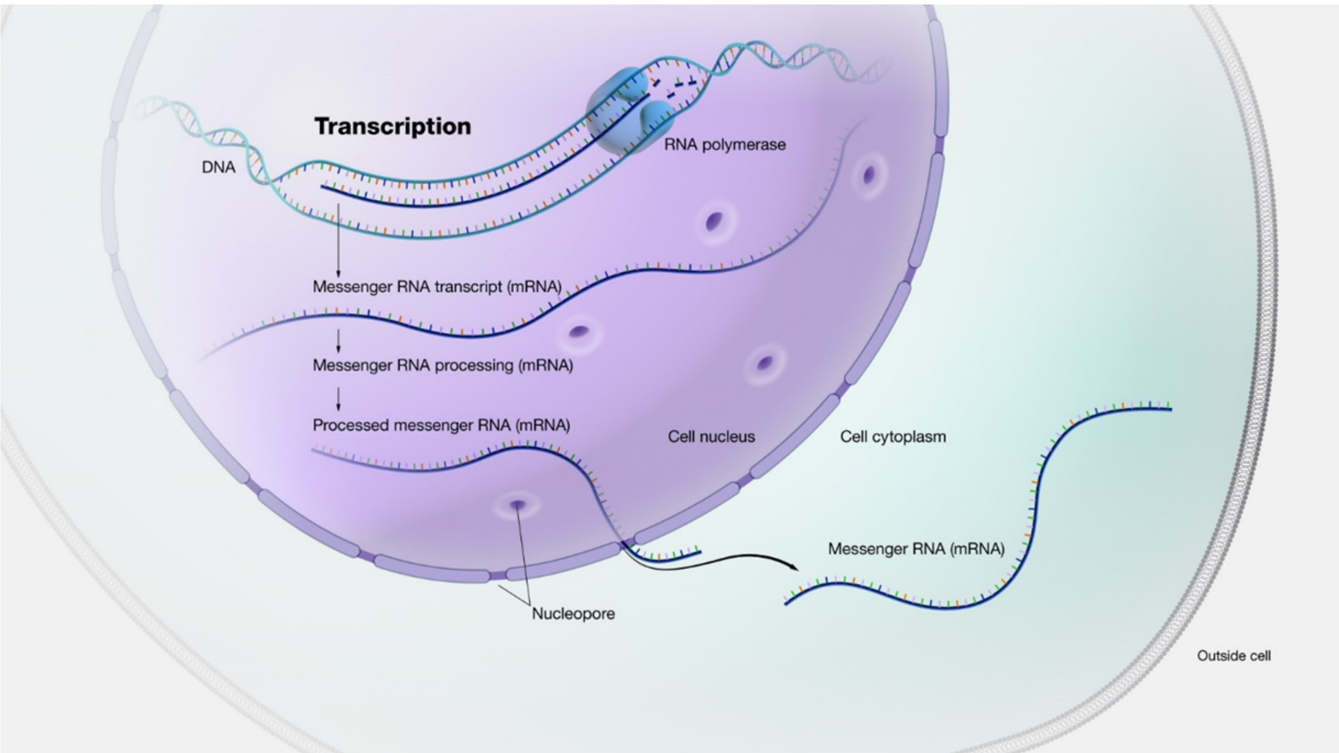


Figure 8.4.3: Illustration of the transcription process. (Copyright; National Human Genome Research Institute, Public domain)

The DNA strand used as a temple for mRNA synthesis s called the **template strand,** and the other is called the **information strand**. The mRNA complements the template strand, i.e., A in the template couples with U and G with C in the mRNA. The sequence of nucleotides in the mRNA is complementary to that of the template strand and the same as in the information strand, except that T in the information strand is replaced with U in the mRNA. Therefore, the primary structure of the information strand is shown as the primary structure of the DNA.

Codons

The gene encodes information about synthesizing a protein with the correct primary structure.

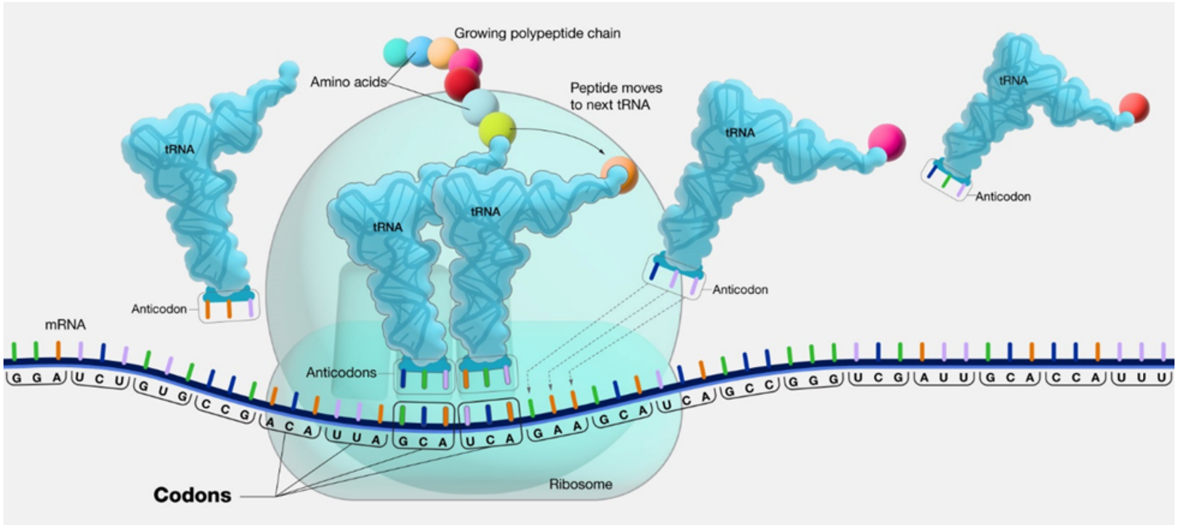


Figure 8.4.4: Illustration of codons on mRNA at the corresponding anticodons on tRNA for the synthesis of proteins. (Copyright; National Human Genome Research Institute, Public domain)

- A code called a **codon** is a sequence of three nucleotides (a trinucleotide) read from a 5' to 3' direction from mRNA, as illustrated in Figure 8.4.4.
- The codons:
  - start from the first appearance of AUG, i.e., adenine-uracil-guanine, reading from 5' to 3' direction on a mRNA,
  - are successive sets of frames of three nucleotides,
  - non-overlapping,
- Since there are four different nucleotides, there are 64 ways to spell out three-letter codons, as shown in Figure 8.4.5.
- Three codons, i.e., UGA, UAA, and UAG, are stop codons signaling the termination of protein synthesis. The remaining 61 specify amino acids.
- Since there are only 20 amino acids, amino acids have more than one codon, except tryptophan and methionine have one codon each. For example, four codons: GGU, GGC, GGA, and GGG, specify glycine.
- Codon AUG has two roles: i) in the middle of a series of codons, it specifies methionine, and ii) at the beginning of an mRNA, it signals the start of protein synthesis by bringing in methionine as the first amino acid, but the first methionine is usually removed later from the beginning (N-terminus) of the protein.

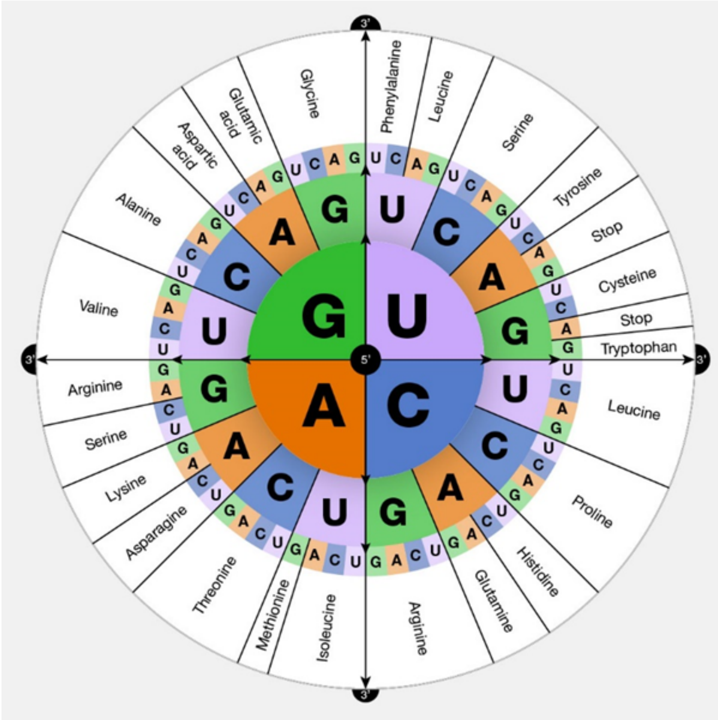


Figure 8.4.5: The 64 codons comprising three consecutive nucleotides in an mRNA read from 5' to 3' direction. The codon is read along the radius from the center to the periphery; e.g., UGG is a codon specifying tryptophan. (Copyright; National Human Genome Research Institute, Public domain)