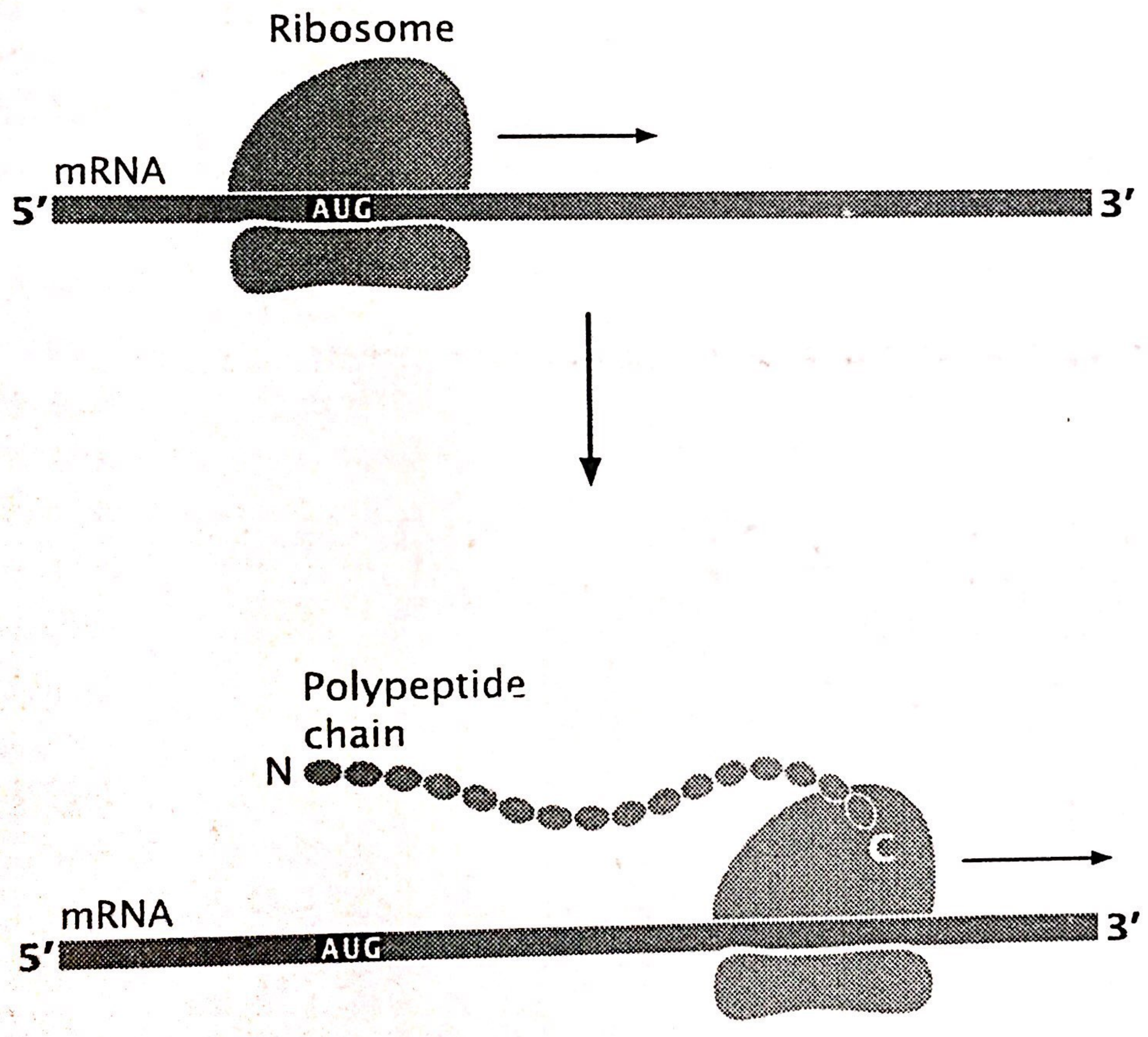
The Process of Translation

Now that we are familiar with the genetic code, we can begin to study the mechanism by which amino acids are assembled into proteins. Because more is known about translation in bacteria, we will focus primarily on bacterial translation. In most respects, eukaryotic translation is similar, although there are some significant differences that will be noted as we proceed through the stages of translation.

Translation takes place on ribosomes; indeed, ribosomes can be thought of as moving protein-synthesizing machines. Through a variety of techniques, a detailed view of the structure of the ribosome has been produced in recent years, which has greatly improved our understanding of the translational process. A ribosome attaches near the 5′ end of an mRNA strand and moves toward the 3′ end, translating the codons as it goes (◀ FIGURE 15.15). Synthesis begins at the amino end of the protein, and the protein is elongated by the addition of new amino acids to the carboxyl end.

Protein synthesis can be conveniently divided into four stages: (1) the binding of amino acids to the tRNAs; (2) initiation, in which the components necessary for translation



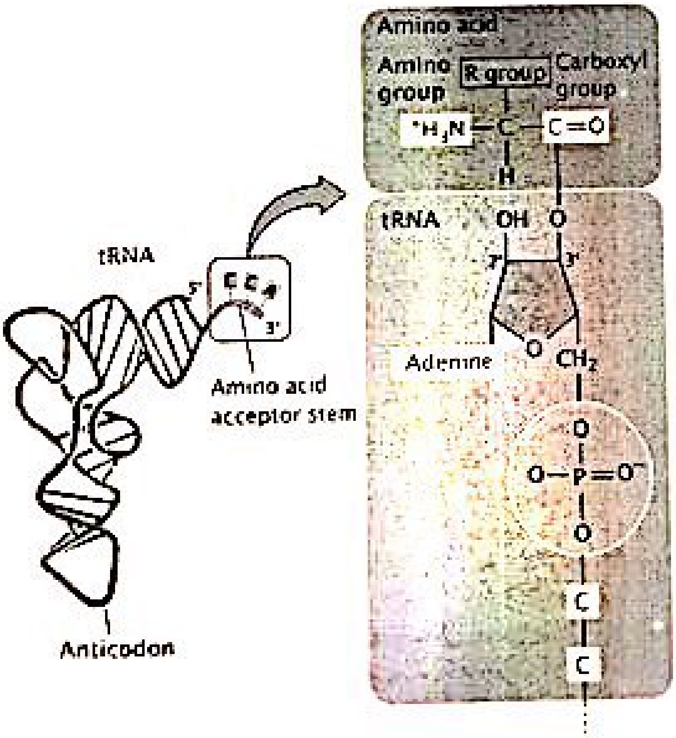
15.15 **The translation of an mRNA molecule takes place on a ribosome.**

are assembled at the ribosome; (3) elongation, in which amino acids are joined, one at a time, to the growing polypeptide chain; and (4) termination, in which protein synthesis halts at the termination codon and the translation components are released from the ribosome.

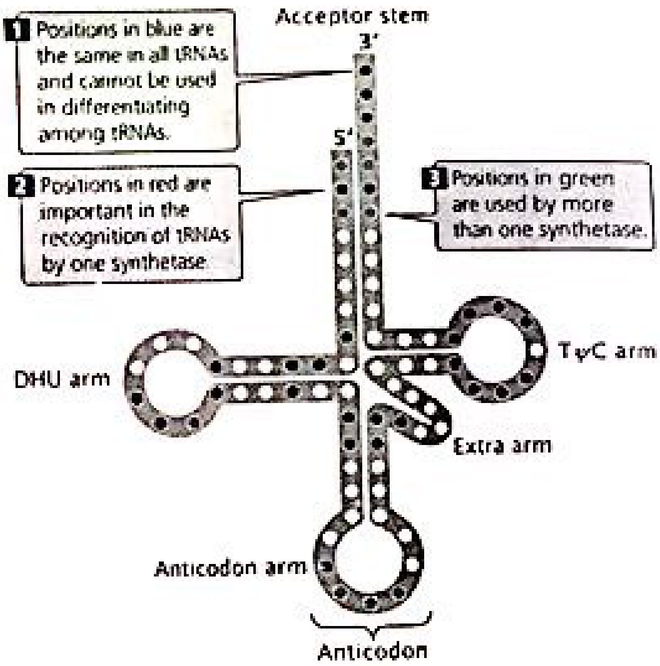
The Binding of Amino Acids to Transfer RNAs

The first stage of translation is the binding of tRNA molecules to their appropriate amino acids. When linked to its amino acid, a tRNA delivers that amino acid to the ribosome, where the tRNA's anticodon pairs with a codon on mRNA. This process enables the amino acids to be joined in the order specified by the mRNA. Proper translation, then, first requires the correct binding of tRNA and amino acid.

As already mentioned, a cell typically possesses from 30 to 50 different tRNAs, and, collectively, these tRNAs are attached to the 20 different amino acids. Each tRNA is specific for a particular kind of amino acid. All tRNAs have the sequence CCA at the 3' end, and the carboxyl group (COO^-) of the amino acid is attached to the 2'- or 3'-hydroxyl group of the adenine nucleotide at the end of the tRNA, (◀FIGURE 15.16). If each tRNA is specific for a particular amino acid but all amino acids are attached to the same nucleotide (A) at the 3' end of a tRNA, how does a tRNA link up with its appropriate amino acid?



◀15.16 **An amino acid attaches to the 3' end of a tRNA. The carboxyl group (COO^-) of the amino acid attaches to the hydroxyl group of the 2'- or 3'- carbon atom of the final nucleotide at the 3' end of the tRNA, in which the base is always an adenine.**



◀15.17 **Certain positions on tRNA molecules are recognized by the appropriate aminoacyl-tRNA synthetase.**

The key to specificity between an amino acid and its tRNA is a set of enzymes called **aminoacyl-tRNA synthetases.** A cell has 20 different aminoacyl-tRNA synthetases, one for each of the 20 amino acids. Each synthetase recognizes a particular amino acid, as well as all the tRNAs that accept that amino acid. Recognition of the appropriate amino acid by a synthetase is based on the different sizes, charges, and R groups of the amino acids. The tRNAs, however, are all similar in tertiary structure. How does a synthetase distinguish among tRNAs?

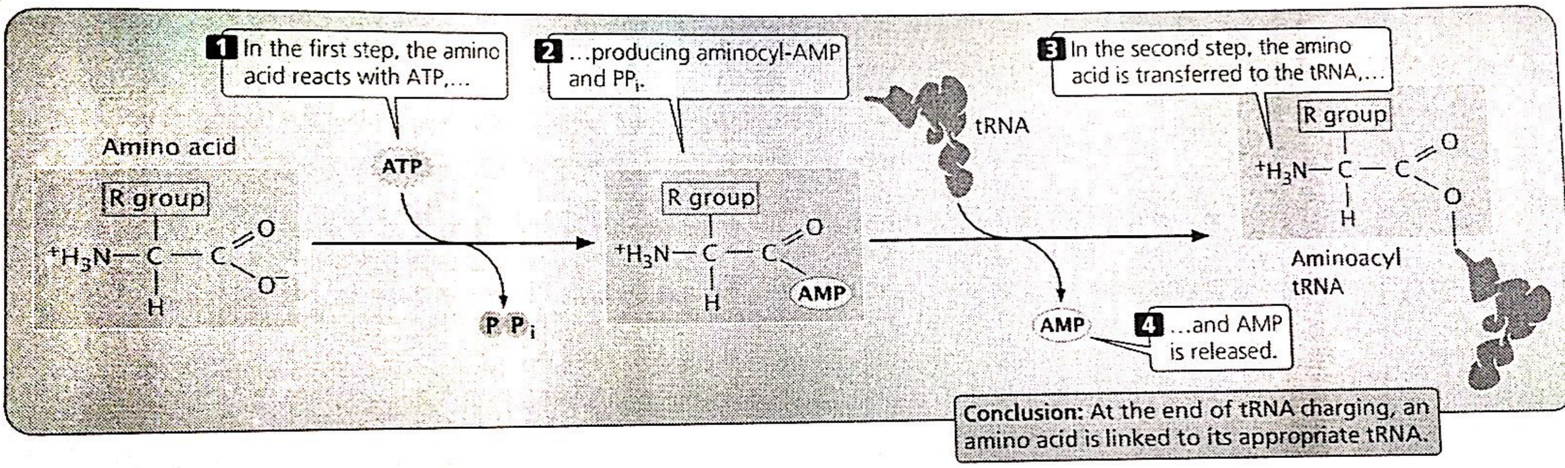
The recognition of tRNAs by a synthetase depends on the differing nucleotide sequences of tRNAs. Researchers have identified which nucleotides are important in recognition by altering different nucleotides in a particular tRNA and determining whether the altered tRNA is still recognized by its synthetase. The results of these studies revealed that the anticodon loop, the DHU-loop, and the acceptor stem are particularly critical for the identification of most tRNAs (◀FIGURE 15.17).

The attachment of a tRNA to its appropriate amino acid (termed **tRNA charging**) requires energy, which is supplied by adenosine triphosphate (ATP):

$$\text{amino acid} + \text{tRNA} + \text{ATP} \longrightarrow \text{aminoacyl-tRNA} + \text{AMP} + PP_i$$

Two phosphates are cleaved from ATP, producing adenosine monophosphate (AMP) and pyrophosphate (PP_i), as well as the aminoacylated tRNA (the tRNA with its attached amino acid). This reaction takes place in two steps (◀ FIGURE 15.18). To identify the resulting aminoacylated tRNA, we write the three-letter abbreviation for the amino acid in front of the tRNA; for example, the amino acid alanine (Ala) attaches to its tRNA ($tRNA^{Ala}$), giving rise to its aminoacyl-tRNA ($Ala\text{-}tRNA^{Ala}$).

Errors in tRNA charging are rare; they occur in only about 1 in 10,000 to 1 in 100,000 reactions. This fidelity is due to the presence of proofreading activity in the synthetases, which detects and removes incorrectly paired amino acids from the tRNAs.



15.18 An amino acid becomes attached to the appropriate tRNA in a two-step reaction.