



Figure 8.1 Enzyme specificity. (A) Trypsin cleaves on the carboxyl side of arginine and (arginine residues) whereas (B) chymotrypsin cleaves on the carboxyl side of tyrosine (tyrosine residues) and (C) pepsin cleaves on the amino side of aspartic acid (aspartic acid residues).

move substrates rather than chemically alter them, use the energy of ATP to transport molecules and ions across the membrane (Chapter 13). The chemical and electrical gradients resulting from the unequal distribution of these molecules and ions are themselves forms of energy that can be used for a variety of purposes, such as sending nerve impulses.

The molecular mechanisms of these energy-transducing enzymes are being unraveled. We will see in subsequent chapters how unidirectional cycles of discrete steps—binding, chemical transformation, and release—lead to the conversion of one form of energy into another.

## 8.2 Free Energy Is a Useful Thermodynamic Function for Understanding Enzymes

Some of the principles of thermodynamics were introduced in Chapter 1—notably the idea of *free energy* ( $G$ ). To understand how enzymes operate, we need to consider only two thermodynamic properties of the reaction: (1) the free-energy difference ( $\Delta G$ ) between the products and reactants and (2) the energy required to initiate the conversion of reactants into products. The former determines whether the reaction will occur spontaneously, whereas the latter determines the rate of the reaction. Enzymes affect only the latter. Let us review some of the principles of thermodynamics as they apply to enzymes.

### The Free-Energy Change Provides Information About the Spontaneity but Not the Rate of a Reaction

As discussed on page 12, the free-energy change of a reaction ( $\Delta G$ ) tells us if the reaction can occur spontaneously:

1. A reaction can occur spontaneously only if  $\Delta G$  is negative. Such reactions are said to be *exergonic*.
2. A system is at equilibrium and no *net* change can take place if  $\Delta G$  is zero.
3. A reaction cannot occur spontaneously if  $\Delta G$  is positive. An input of free energy is required to drive such a reaction. These reactions are termed *endergonic*.
4. The  $\Delta G$  of a reaction depends only on the free energy of the products (the final state) minus the free energy of the reactants (the initial state). The  $\Delta G$  of a reaction is independent of the path (or molecular mechanism) of the transformation. The mechanism of a reaction has no effect on  $\Delta G$ . For example, the  $\Delta G$  for the oxidation of glucose to  $\text{CO}_2$  and  $\text{H}_2\text{O}$  is the same whether it occurs by combustion or by a series of enzyme-catalyzed steps in a cell.
5. The  $\Delta G$  provides no information about the rate of a reaction. A negative  $\Delta G$  indicates that a reaction *can* occur spontaneously, but it does not signify whether it will proceed at a perceptible rate. As will be discussed shortly (Section 8.3), the rate of a reaction depends on the *free energy of activation* ( $\Delta G^\ddagger$ ), which is largely unrelated to the  $\Delta G$  of the reaction.

### The Standard Free-Energy Change of a Reaction Is Related to the Equilibrium Constant

As for any reaction, we need to be able to determine  $\Delta G$  for an enzyme-catalyzed reaction to know whether the reaction is spontaneous or an input