In the first step, an α-D-galactopyranose anomer occupies its spot inside the cavity of an enzyme (depicted as a curvy line), oriented in one geometry through intermolecular interactions such as hydrogen bonding. Another reagent, named uracil triphosphate (UTP), is situated and held within bonding distance. A basic site on the enzyme deprotonates the hydroxyl group and an S_N2 reaction with the UTP takes place to give α-D-galactopyranose-UDP. Analogous to the chemical laboratory example, the purpose of the UTP reaction is to turn the anomeric hydroxyl group into a leaving group that is placed in the axial position.

In the second step, another enzyme holds the α-D-galactopyranose-UDP and a molecule of glucopyranose within bonding distance, and with a basic site that can deprotonate the carbon-4 hydroxyl group as another S_N2 reaction takes place, forming the lactose molecule.

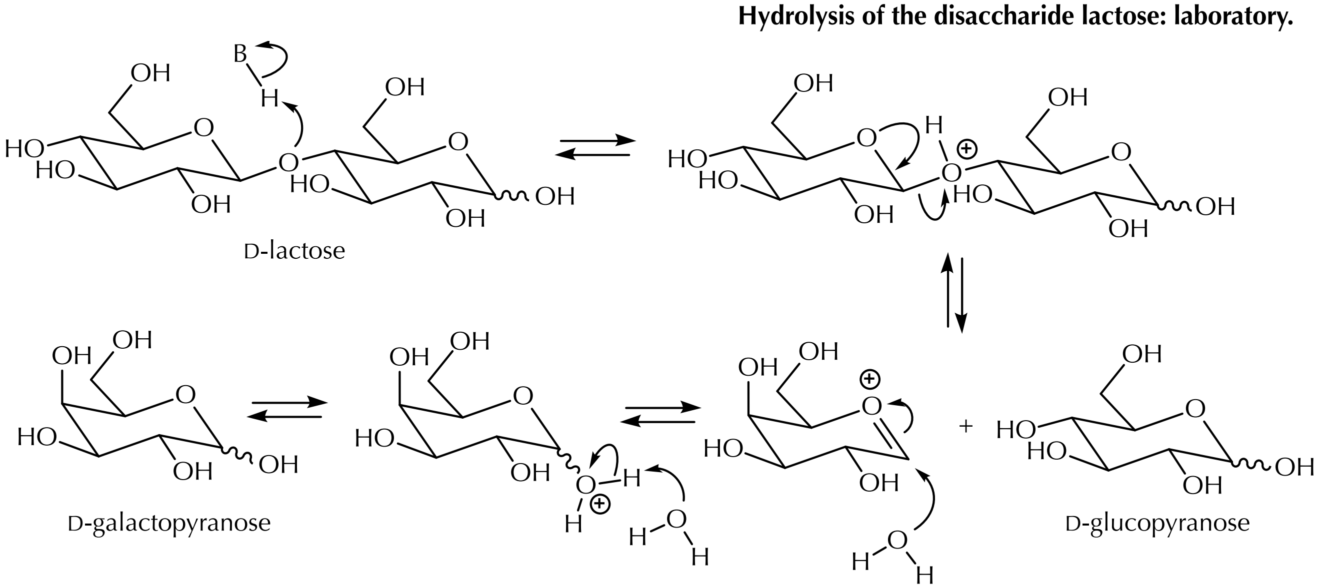
More detail about the structure and function of enzymes is included in the next two chapters. The purpose for giving this overview is for you to compare and contrast the laboratory method (Figure 1645) with the biochemistry (Figure 1646). In both cases, the fundamental strategy is the same: Carry out an S_N2 reaction with the C-4 hydroxyl of glucose on the anomeric carbon of galactose. The biochemical pathway, which evolved over millions of years, requires the enzymatic catalysts and an organism to support the cells. The details of the laboratory synthesis took a few decades to develop and can be carried out in beakers and flasks.

Industrially, thanks to cows, we rely on the biochemical synthesis of lactose. Millions of tons of lactose, which makes up between 2–8% of milk, is provided by the dairy industry. When milk is treated with mild acids, the dissolved proteins precipitate (curdle) and can be collected by filtration. This solid material is called the curd, and it is the foundation for making cheese. The remaining liquid (called the whey) contains the dissolved lactose, which can be isolated by crystallization and used in a variety of commercial products. Homemade cheeses such as ricotta and mascarpone are easily prepared exactly the same way. Boiling a mixture of milk and cream (or cream only, for mascarpone) with a vinegar and lemon juice mixture will rapidly curdle, and the mixture can be filtered using cheesecloth (of course!).

The mechanism for the laboratory hydrolysis reaction of lactose is the normal S_N1 reaction of acetals with water used to restore a hemiacetal (Figure 1647).

Figure 1647

Hydrolysis of the disaccharide lactose: laboratory.



Interestingly enough, depending on your genetics, it might be easier for you to carry out this hydrolysis in the laboratory than it is in your body. As with all biochemical processes, there is an enzyme, called lactase, that catalyzes the hydrolysis reaction of lactose in living organisms. Schematically, the enzymatic