and then to an organic acid which is further converted to acetyl-CoA, which is metabolized by the TCA cycle.

Oxidation of aromatic hydrocarbons takes place by the action of oxygenases and proceeds much slower than those of aliphatic hydrocarbons. Cathecol is the key intermediate in this oxidation sequence and can be further broken down ultimately to acetyl-CoA or TCA cycle intermediates. Aerobic metabolism of benzene is depicted below:

$$\begin{array}{ccccccc} \text{benzene} & \longrightarrow & \text{cathecol} & \longrightarrow & \textit{cis-cis}\text{-muconate} & \longrightarrow & \beta\text{-keto adipate} \\ & & & & & & \downarrow \\ & & & & & & \text{acetyl-CoA} + \text{succinate} \end{array} \tag{5.15}$$

Anaerobic metabolism of hydrocarbons is more difficult. Only a few organisms can metabolize hydrocarbons under anaerobic conditions. They cleave the C–C bonds and saturate with hydrogen to yield methane.

5.9. OVERVIEW OF BIOSYNTHESIS

The TCA cycle and glycolysis are critical catabolic pathways and also provide important precursors for the biosynthesis of amino acids, nucleic acids, lipids, and polysaccharides. Although many additional pathways exist, we will describe just two more, one in the context of biosynthesis and the other under anaerobic metabolism.

The first is the *pentose–phosphate pathway* or *hexose–monophosphate pathway* (HMP) (see Fig. 5.7). Although this pathway produces significant reducing power, which could be used, in principle, to supply energy to the cell, its primary role is to provide carbon skeletons for biosynthetic reactions and the reducing power necessary to support anabolism. Normally, NADPH is used in biosynthesis, whereas NADH is used in energy production. This pathway provides an array of small organic compounds with three, four, five, and seven carbon atoms. These compounds are particularly important for the synthesis of ribose, purines, coenzymes, and the aromatic amino acids. The glyceraldehyde-3-phosphate formed can be oxidized to yield energy through conversion to pyruvate and further oxidation of pyruvate in the TCA cycle.

A vital component of biosynthesis, which consumes a large amount of cellular building blocks, is the production of amino acids. Many amino acids are also important commercial products, and the alteration of pathways to induce overproduction (see Chapter 4) is critical to commercial success. The 20 amino acids can be grouped into various families. Figure 5.8 summarizes these families and the compounds from which they are derived. The amino acid, histidine, is not included in Fig. 5.8. Its biosynthesis is fairly complicated and cannot be easily grouped with the others. However, ribose-5-phosphate from HMP is a key precursor in its synthesis.

In addition to the synthesis of amino acids and nucleic acids, the cell must be able to synthesize lipids and polysaccharides. The key precursor is acetyl-CoA (see Fig. 5.5 for the TCA cycle). Fatty acid synthesis consists of the stepwise buildup of acetyl-CoA. Also, CO_2 is an essential component in fatty acid biosynthesis. Acetyl-CoA and CO_2 produce malomyl-CoA, which is a three-carbon-containing intermediate in fatty acid synthesis. This requirement for CO_2 can lengthen the start-up phase (or lag phase; see Chapter 6) for com-