Ethanol formation during baker's yeast fermentation may be reduced or eliminated by culture with intermittent addition of glucose or by using carbon sources other than sucrose or glucose that support less rapid growth.

The major metabolic pathways and products of various microorganisms will be briefly covered in this chapter. Metabolic pathways are subgrouped as aerobic and anaerobic metabolism.

There are two key concepts in our discussion. *Catabolism* is the intracellular process of degrading a compound into smaller and simpler products (e.g., glucose to CO_2 and H_2O). Catabolism produces energy for the cell. *Anabolism* is involved in the synthesis of more complex compounds (e.g., glucose to glycogen) and requires energy.

5.2. BIOENERGETICS

Living cells require energy for biosynthesis, transport of nutrients, motility, and maintenance. This energy is obtained from the catabolism of carbon compounds, mainly carbohydrates. Carbohydrates are synthesized from CO_2 and H_2O in the presence of light by photosynthesis. The sun is the ultimate energy source for the life processes on earth.[†]

Metabolic reactions are fairly complicated and vary from one organism to another. However, these reactions can be classified in three major categories. A schematic diagram of these reactions is presented in Fig. 5.1. The major categories are (I) degradation of nutrients, (II) biosynthesis of small molecules (amino acids, nucleotides), and (III) biosynthesis of large molecules. These reactions take place in the cell simultaneously. As a result of metabolic reactions, end products are formed and released from the cells. These end products (organic acids, amino acids, antibiotics) are often valuable products for human and animal consumption.

Energy in biological systems is primarily stored and transferred via adenosine triphosphate (ATP), which contains high-energy phosphate bonds.

The active form of ATP is complexed with Mg^{2+}. The standard free-energy charge for the hydrolysis of ATP is 7.3 kcal/mol. The actual free-energy release in the cell may be substantially higher because the concentration of ATP is often much greater than that for ADP.

$$\mathrm{ATP} + \mathrm{H_2O} \rightleftharpoons \mathrm{ADP} + \mathrm{P}_i, \quad \Delta G^\circ = -7.3 \text{ kcal/mol} \tag{5.1}$$

Biological energy is stored in ATP by reversing this reaction to form ATP from ADP and P_i. Similarly, ADP dissociates to release energy.

$$\mathrm{ADP} + \mathrm{H_2O} \rightleftharpoons \mathrm{AMP} + \mathrm{P}_i, \quad \Delta G^\circ = -7.3 \text{ kcal/mol} \tag{5.2}$$

Analog compounds of ATP, such as guanosine triphosphate (GTP), uridine triphosphate (UTP), and cytidine triphosphate (CTP), also store and transfer high-energy phosphate bonds, but not to the extent of ATP. High-energy phosphate compounds produced during metabolism, such as phosphoenol pyruvate and 1,3-diphosphoglycerate, transfer

[†]The only exception is near some thermal vents at the bottom of the ocean, where nonphotosynthetic ecosystems exist independently of sunlight.