The term *glycolysis* comes from the two Greek words *glykys* (which means "sweet," thus referring to sugar) and *lysis* (which means "disintegration"). Glycolysis is an anaerobic process where glucose with six carbon atoms is split into two smaller molecules with three carbon atoms each. It is also known as the *Embden-Meyerhof pathway* in recognition of Gustav Georg Embden (1874–1933) and Otto Meyerhof (1884–1951). They are both Germans, a physiological chemist and a biochemist, respectively, who separately determined the sequence of reactions in glycolysis.

THE STEPS OF GLYCOLYSIS

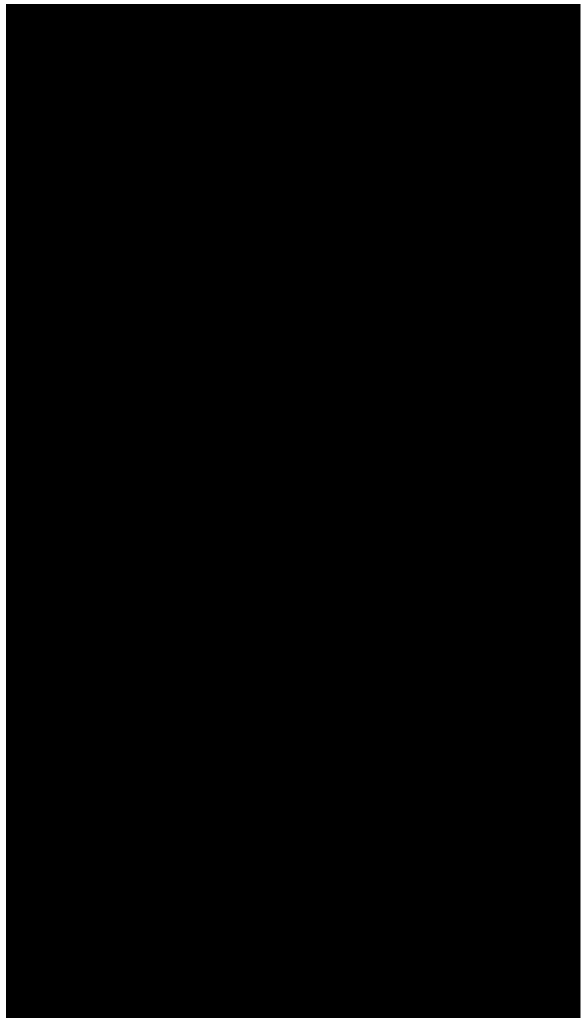
Figure 8.3 shows the 10 reactions in the pathway that are all catalyzed by enzymes. These occur in the cytosol of all organisms, whether eukaryotes or prokaryotes.

The 10 chemical reactions in glycolysis are as follows:

Step 1. In a reaction catalyzed by hexokinase, the six-carbon glucose gains a phosphate group that comes from ATP hydrolysis. The product of this reaction is glucose-6-phosphate, which means that the phosphate group is attached to carbon 6 of glucose.

Step 2. Phosphoglucose isomerase converts glucose-6-phosphate into fructose-6-phosphate.

Step 3. Another round of ATP hydrolysis is catalyzed by phosphofructose kinase, releasing a phosphate group that is attached to carbon 1 of the substrate. Thus, the product has two phosphate groups and is called fructose 1, 6-bisphosphate.



The first five reactions of glycolysis make up the *energy investment phase* because two molecules of ATP are invested or spent by the cell in order to add two phosphate groups to glucose (see steps 1 and 3). This phase is also where the 6-carbon molecule (fructose 1, 6-bisphosphate) is actually split into two different 3-carbon molecules (see step 4).

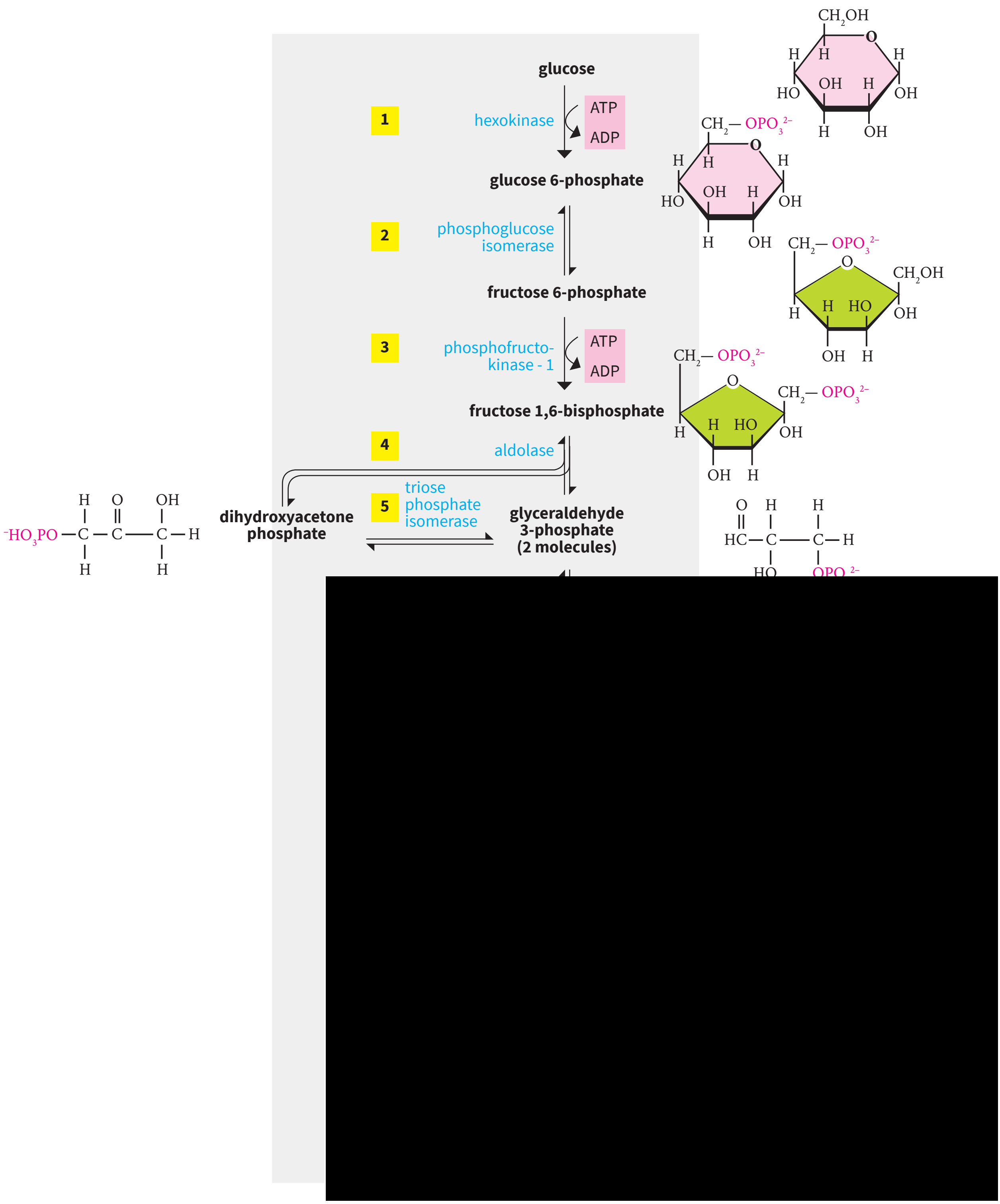


Fig. 8.3 The chemical reactions in glycolysis split a molecule of glucose into two molecules of pyruvate and release high-energy compounds.

Step 6. In a redox reaction catalyzed by G3P dehydrogenase, the two molecules of G3P lose electrons and gain another phosphate group, forming two molecules of 1, 3-bisphosphoglycerate. The released electrons reduce two molecules of *nicotinamide adenine dinucleotide* (NAD^+) to form two NADH. NAD^+ is an electron carrier derived from niacin or vitamin B_3. It accepts two electrons and one hydrogen upon reduction. When NADH is oxidized back to NAD^+, the released electrons provide the energy needed for ATP synthesis via oxidative phosphorylation.

Step 7. Each of the two molecules of 1, 3-bisphosphoglycerate is dephosphorylated in a reaction catalyzed by phosphoglycerate kinase. This results in two products with only one phosphate group each, 3-phosphoglycerate. The two phosphate groups released from the two substrates are gained by two ADP to produce two ATP molecules.

Step 8. Phosphoglycerate mutase catalyzes the conversion of the two 3-phosphoglycerate into two molecules of 2-phosphoglycerate.

[redacted]

After the energy investment phase, the second half of glycolysis is the *energy payoff phase*. Substrate-level phosphorylation takes place twice, producing a total of four ATP molecules (see steps 7 and 10). In the first half of the process, two ATP molecules were initially spent by the cell, but the second half gains four ATP molecules. The cell made a profit of two ATP molecules.

Glycolysis may be summarized by the following equation:

$$\text{Glucose (6 carbon)} + 2\,ADP + 2\,P_i + 2\,NAD^+ \rightarrow 2\ \text{pyruvate (3 carbon each)} + 2\,ATP + 2\,NADH + 2\,H^+ + 2\,H_2O$$

Notice that no CO_2 is released during glycolysis and the six carbon atoms in glucose are still intact in the two molecules of pyruvate. Energy is still stored in the bonds of the pyruvate molecule. This can be extracted when pyruvate is oxidized.

REGULATION OF GLYCOLYSIS

When the cell has enough ATP, a molecule of ATP binds to the enzyme phosphofructokinase, which catalyzes the third step of glycolysis. The binding of ATP changes the form of the enzyme, causing it to become nonfunctional. This prevents the overproduction of ATP. This process, where a biochemical reaction slows down when there is too much of the product is known as *negative feedback inhibition*. Metabolic reactions are usually controlled by feedback inhibition to ensure that the cell produces the right amount of the product at the right time.