Dr. Mustafa Mohammed & Dr. Marowa Hashim

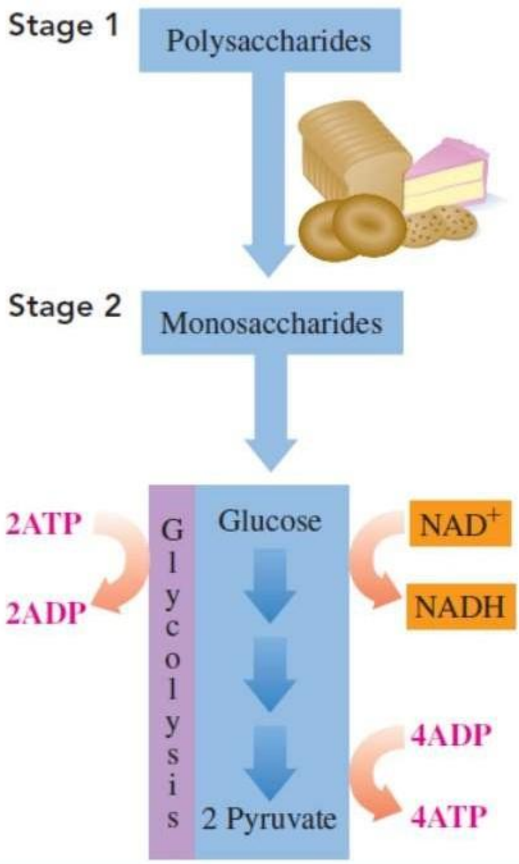
Carbohydrate Metabolism

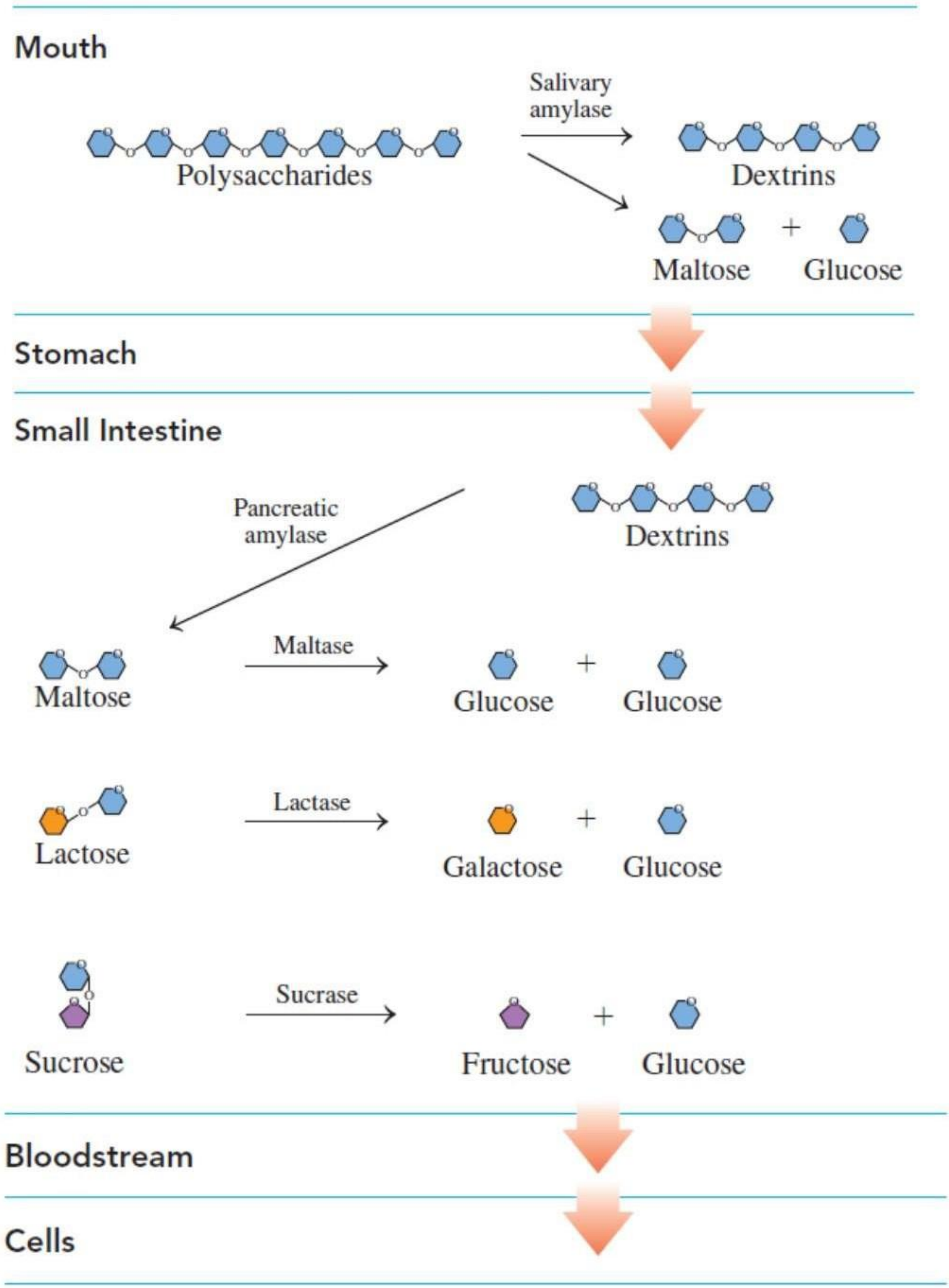
Digestion of Carbohydrates

The digestion of carbohydrates begins in the mouth, where the enzymes produced in the salivary glands hydrolyze some of the α-glycosidic bonds in starch (amylose and amylopectin) producing maltose, glucose, and smaller polysaccharides called dextrins, which contain three to eight glucose units. After swallowing, the partially digested starches enter the acidic environment of the stomach, where the low pH stops carbohydrate digestion.

When the food-gastric juice mixture enters the small intestine, the pancreas releases sodium bicarbonate to neutralize the HCl.

In the small intestine, which has a pH of about 8, enzymes produced in the pancreas hydrolyze the remaining dextrins to maltose and glucose. Then enzymes produced in the mucosal cells that line the small intestine hydrolyze maltose as well as lactose and sucrose. The resulting monosaccharides are absorbed through the intestinal wall into the bloodstream, which carries them to the liver, where the hexoses fructose and galactose are converted to glucose which then release energy by glycolysis pathway. Glucose is the primary energy source for muscle contractions, red blood cells, and the brain.




Mouth
Salivary amylase
Polysaccharides
Dextrins
Maltose
Glucose
Stomach
Small Intestine
Pancreatic amylase
Dextrins
Maltose
Maltase
Glucose
Glucose
Lactose
Lactase
Galactose
Glucose
Sucrose
Sucrase
Fructose
Glucose
Bloodstream
Cells

Glycolysis

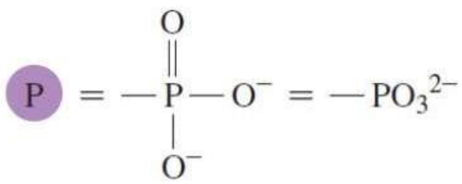
Glycolysis, also known as the Embden-Meyerhof Pathway, is an important part of the catabolic process by which the body gets energy from carbohydrates. It consists of a series of ten reactions, with the net result being the conversion of a glucose molecule into two molecules of pyruvate. All enzymes for glycolysis are present in the cellular cytoplasm.

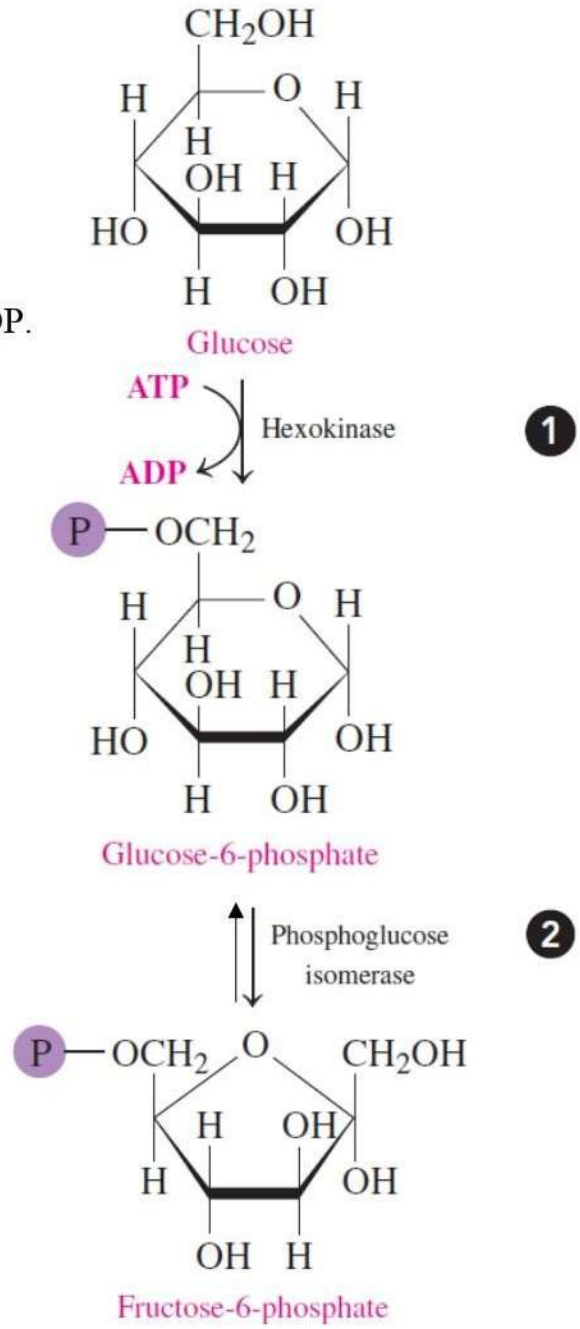
The ten reactions of glycolysis catalyzed by these enzymes are represented in the Figure below.

Energy-consuming Reactions 1 to 5

Reaction 1 Phosphorylation

In the initial reaction, a phosphate group from ATP is added to glucose to form glucose-6-phosphate and ADP.



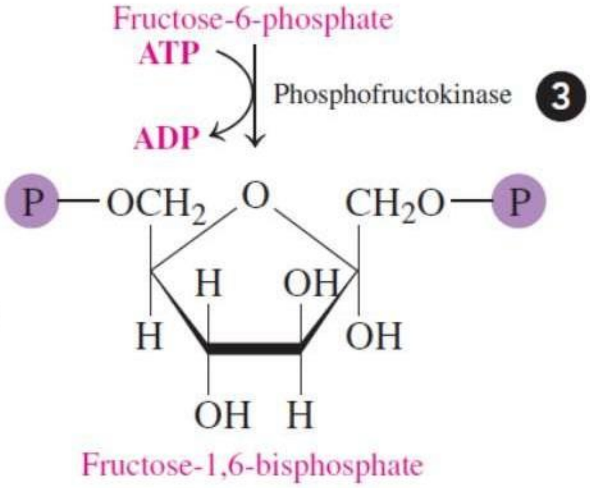


Reaction 2 Isomerization

The glucose-6-phosphate, the aldose from reaction 1, undergoes isomerization to fructose-6-phosphate, which is a ketose.

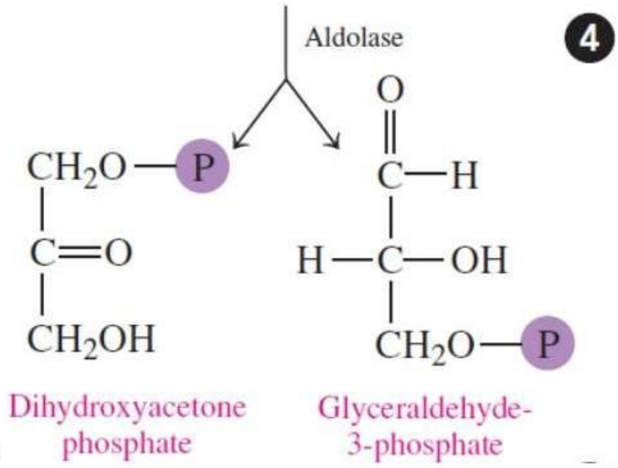
Reaction 3 Phosphorylation

The hydrolysis of another ATP provides a second phosphate group, which converts fructose-6-phosphate to fructose-1,6-bisphosphate. The word *bisphosphate* is used to show that the two phosphate groups are on different carbons in fructose and not connected to each other.



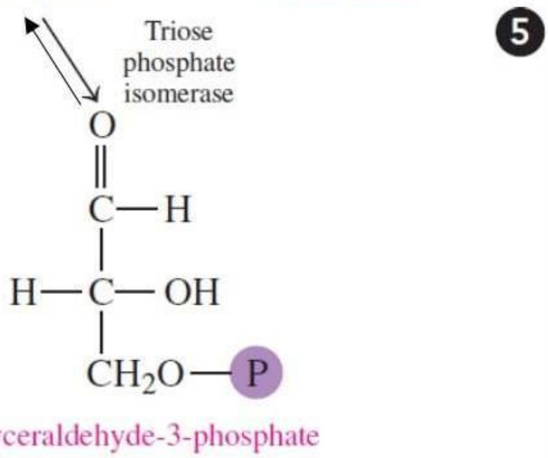
Reaction 4 Cleavage

Fructose-1,6-bisphosphate is split into two three-carbon phosphate isomers: dihydroxyacetone phosphate and glyceraldehyde-3-phosphate.



Reaction 5 Isomerization

Because dihydroxyacetone phosphate is a ketone, it cannot undergo further oxidation.However, it undergoes isomerization to provide a second molecule of glyceraldehyde-3-phosphate, which can be oxidized. Now all six carbon atoms from glucose are contained in two identical triose phosphates.

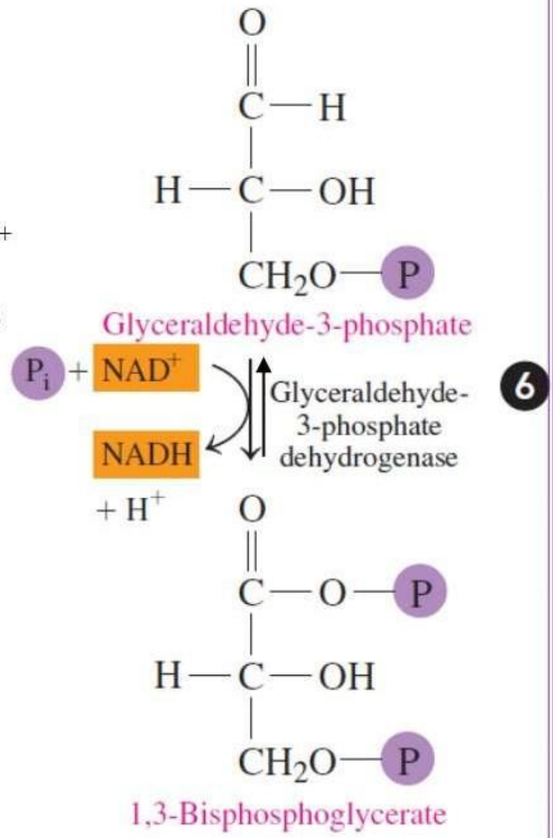


Energy-Generating Reactions 6 to 10

the two molecules of glyceraldehyde-3-phosphateproduced in step 5 are undergoing the same reactions

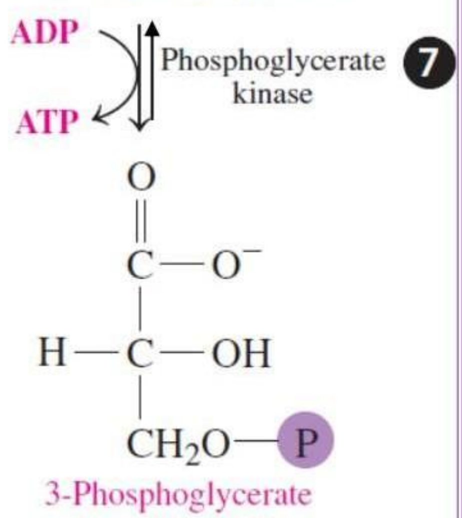
Reaction 6 Oxidation and Phosphorylation

The aldehyde group of each glyceraldehyde-3-phosphate is oxidized to a carboxyl group, while the coenzyme NAD^+ is reduced to NADH and H+. A phosphate group (Pi) adds to each of the new carboxyl groups to form two molecules of the high-energy compound 1,3-bisphosphoglycerate.



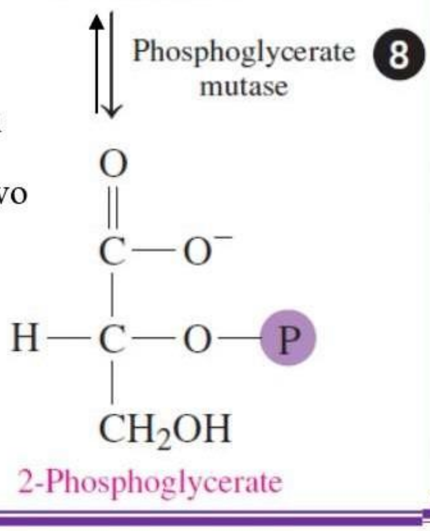
Reaction 7 Phosphate Transfer

A phosphate group from each 1,3-bisphosphoglycerate is transferred to two ADP molecules, yielding two molecules of the high-energy compound ATP. At this point in glycolysis, two ATP are produced, which balance the two ATP consumed



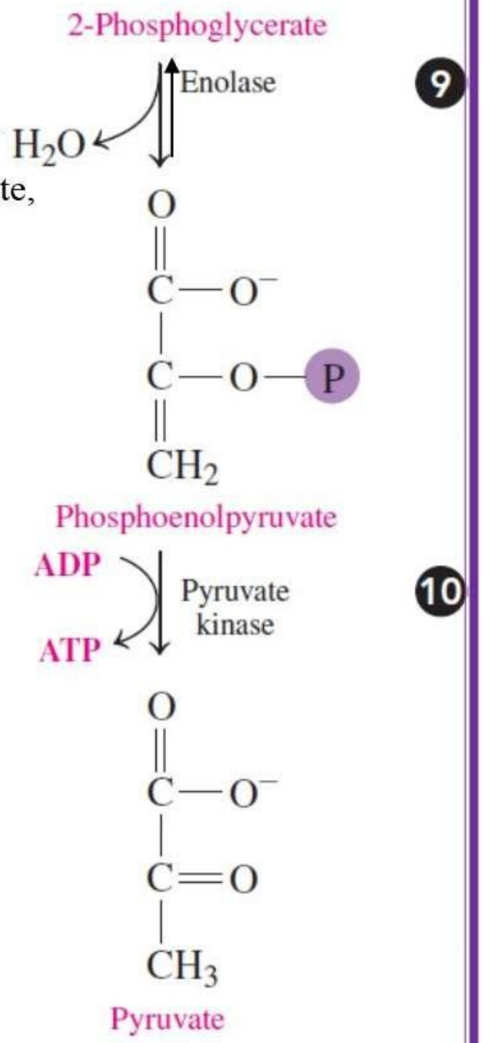
Reaction 8 Isomerization

Two 3-phosphoglycerate molecules undergo isomerization, which moves the phosphate group from carbon 3 to carbon 2, yielding two molecules of 2-phosphoglycerate.



Reaction 9 Dehydration

Each of the phosphoglycerate molecules undergoes dehydration (loss of water), producing two molecules of phosphoenolpyruvate, a high-energy compound.



Reaction 10 Phosphate Transfer

In a second direct phosphorylation, phosphate groups from two phosphoenolpyruvate molecules are transferred to two ADP to form two pyruvate and two ATP.

The addition of all these reactions gives a net reaction for glycolysis:

$$\underset{\text{Glucose}}{C_6H_{12}O_6} + 2NAD^+ + 2ADP + 2P_i \longrightarrow \underset{\text{Pyruvate}}{2CH_3-\overset{\overset{\displaystyle O}{\|}}{C}-COO^-} + 2NADH + 2ATP + 4H^+ + 2H_2O$$

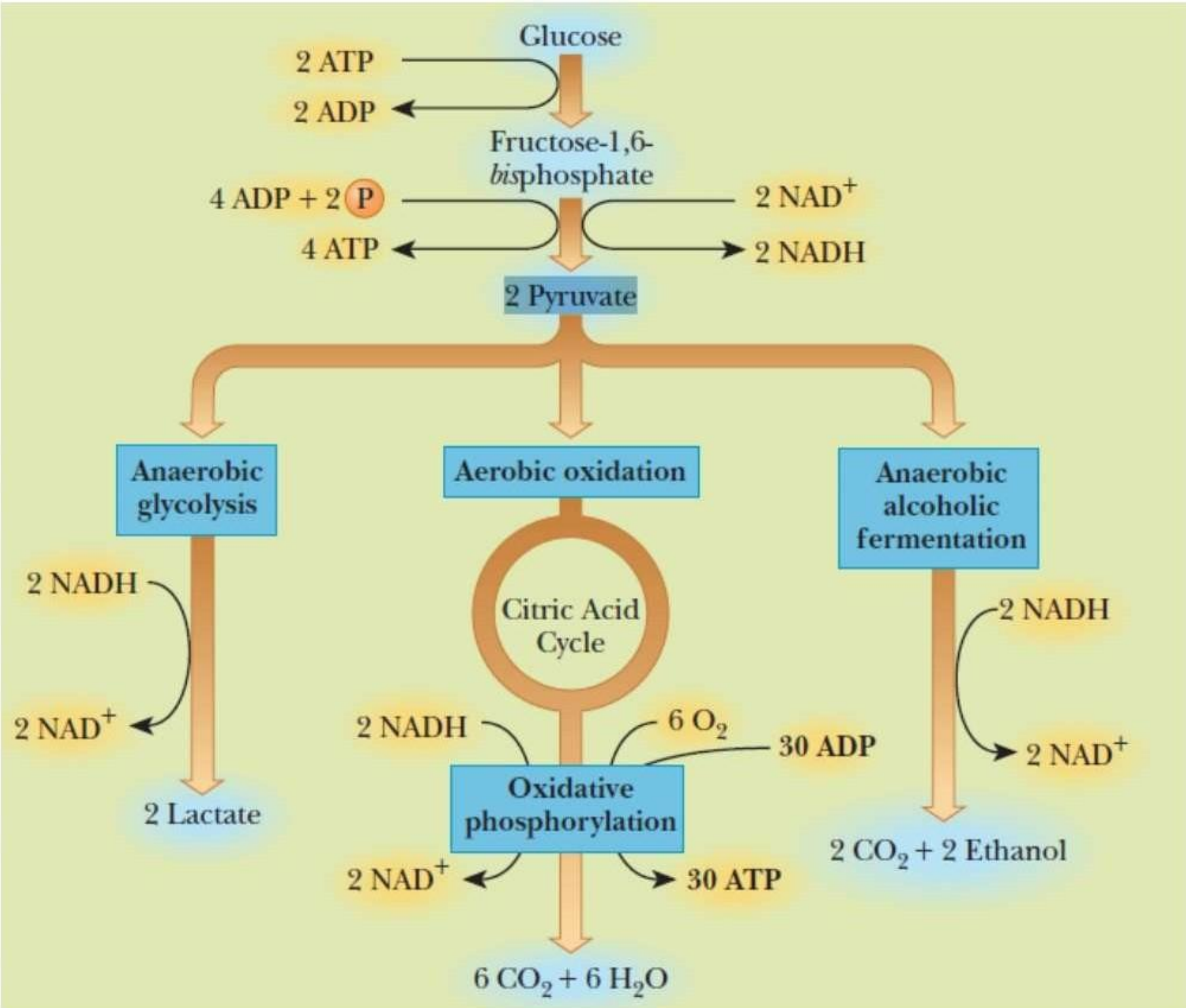
This equation indicates a net gain of 2 mol of ATP for every mole of glucose converted to pyruvate. In addition, 2 mol of the coenzyme NADH is formed when NAD^+ serves as an oxidizing agent in glycolysis. Fructose and galactose from digested food are both converted into intermediates that enter into the glycolysis pathway.

Fructose enters glycolysis as dihydroxyacetone phosphate and glyceraldehyde- 3-phosphate, whereas galactose is metabolized to glucose and enters in the form of glucose-6-phosphate.

The Fate of Pyruvate

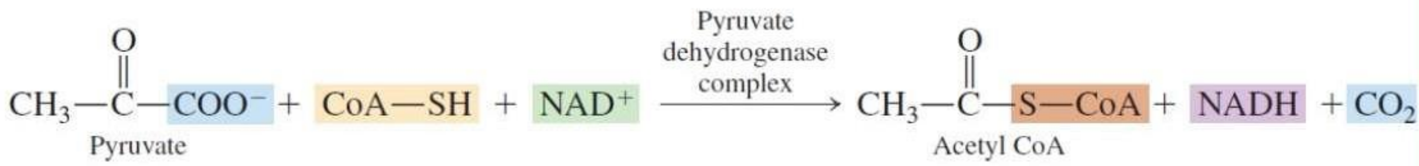
The sequence of reactions that converts glucose to pyruvate is very similar in all organisms and in all kinds of cells. However, the fate of the pyruvate as it is used to generate energy is variable. Three different fates of pyruvate are considered here:

1- Oxidation to Acetyl CoA
2- Reduction to Lactate (Lactate fermentation)
3- Reduction to Ethanol (Alcohol fermentation)



1-Oxidation to Acetyl CoA

The mitochondrial membrane is permeable to pyruvate formed by glycolysis in the cytoplasm, and under **aerobic** conditions (oxygen-rich), pyruvate is converted inside the mitochondria to acetyl CoA.

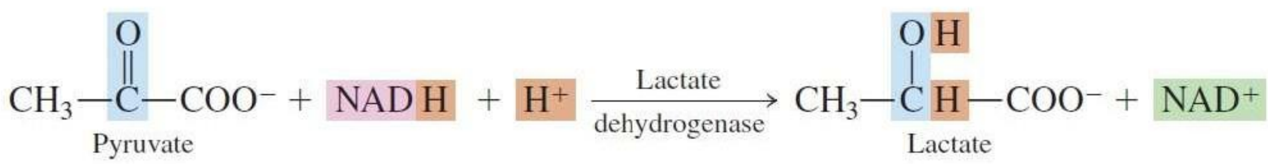


Acetyl CoA formed in this reaction can enter the citric acid cycle on its way to complete oxidation to CO_2.

2- Reduction to Lactate (Lactate fermentation)

Under anaerobic conditions, such as those which include exercise so hard that your lungs and circulatory system can't supply enough oxygen to the working muscles for the reoxidation of NADH to NAD^+, thus the aerobic pathways are not able to supply enough ATP to working muscles. But the muscles still need energy. Under these anaerobic conditions, lactate fermentation begins through reducing pyruvate to lactate as a means of regenerating NAD^+.

NADH is the reducing agent for this process. As pyruvate is reduced, NADH is oxidized, and NAD^+ is again available, permitting glycolysis to continue.



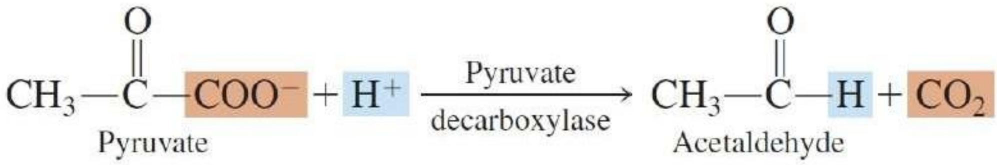
The accumulation of lactate causes the muscles to tire and become sore.

3-Reduction to Ethanol (Alcohol fermentation)

Under anaerobic conditions, several simple organisms, including yeast, possess the ability to conversion of pyruvate to ethanol and carbon dioxide and to regenerate NAD^+ , a process is called **ethanol fermentation**.

Ethanol fermentation is a useful process through which bread, wine, and cheese is produced.

The first step involves the decarboxylation of pyruvate to form acetaldehyde:



The second step involves acetaldehyde reduction to produce ethanol: