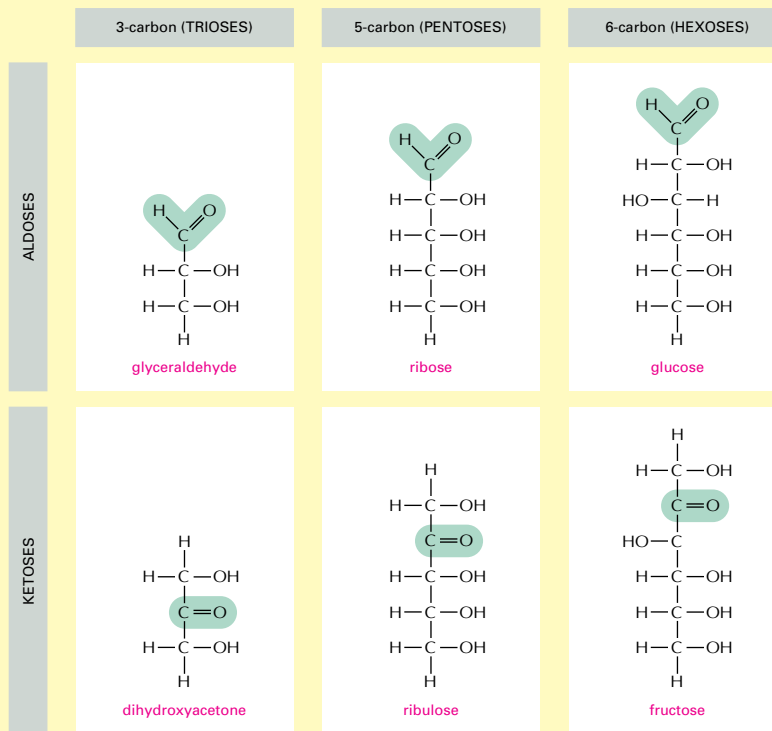


Outline of Sugar Types Found in Cells - Part 1

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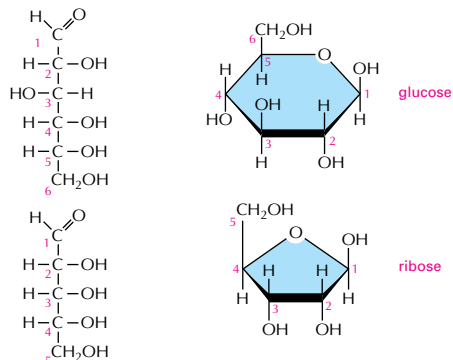
MONOSACCHARIDES

Monosaccharides usually have the general formula $(CH_2O)_n$, where n can be 3, 4, 5, 6, 7, or 8, and have two or more hydroxyl groups. They either contain an aldehyde group ($-C \begin{smallmatrix} O \\ // \\ H \end{smallmatrix}$) and are called aldoses or a ketone group ($>C=O$) and are called ketoses.



RING FORMATION

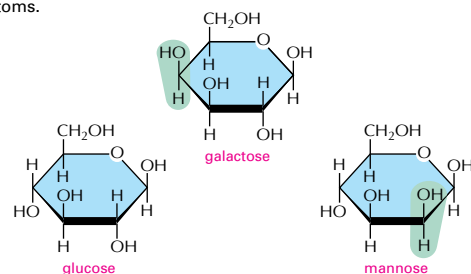
In aqueous solution, the aldehyde or ketone group of a sugar molecule tends to react with a hydroxyl group of the same molecule, thereby closing the molecule into a ring.



Note that each carbon atom has a number.

ISOMERS

Many monosaccharides differ only in the spatial arrangement of atoms—that is, they are **isomers**. For example, glucose, galactose, and mannose have the same formula ($C_6H_{12}O_6$) but differ in the arrangement of groups around one or two carbon atoms.



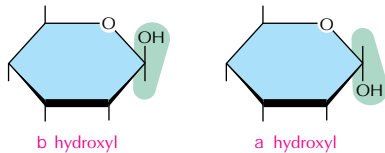
These small differences make only minor changes in the chemical properties of the sugars. But they are recognized by enzymes and other proteins and therefore can have important biological effects.

Outline of Sugar Types Found in Cells - Part 2

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a AND b LINKS

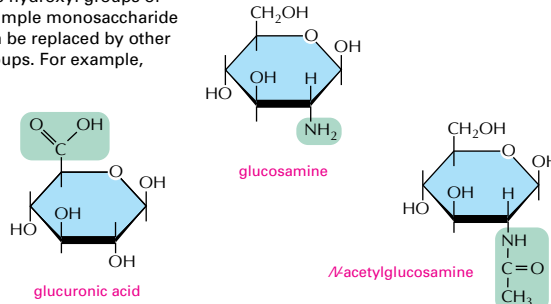
The hydroxyl group on the carbon that carries the aldehyde or ketone can rapidly change from one position to the other. These two positions are called a and b.



As soon as one sugar is linked to another, the a or b form is frozen.

SUGAR DERIVATIVES

The hydroxyl groups of a simple monosaccharide can be replaced by other groups. For example,



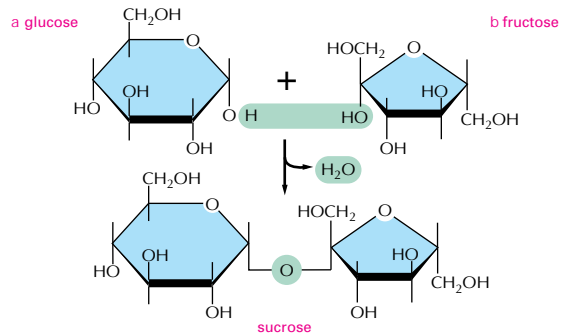
DISACCHARIDES

The carbon that carries the aldehyde or the ketone can react with any hydroxyl group on a second sugar molecule to form a **disaccharide**.

Three common disaccharides are

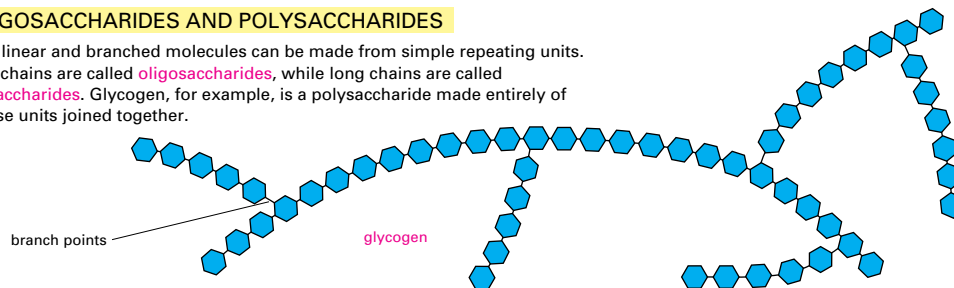
- maltose (glucose + glucose)
- lactose (galactose + glucose)
- sucrose (glucose + fructose)

The reaction forming sucrose is shown here.



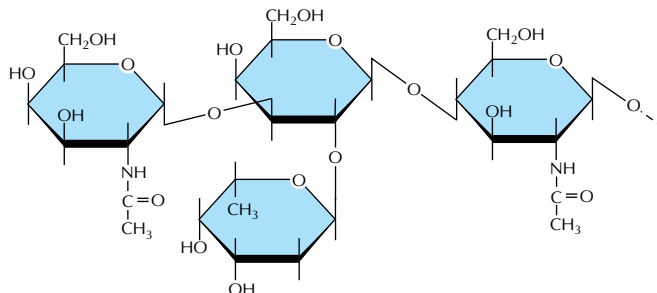
OLIGOSACCHARIDES AND POLYSACCHARIDES

Large linear and branched molecules can be made from simple repeating units. Short chains are called **oligosaccharides**, while long chains are called **polysaccharides**. Glycogen, for example, is a polysaccharide made entirely of glucose units joined together.



COMPLEX OLIGOSACCHARIDES

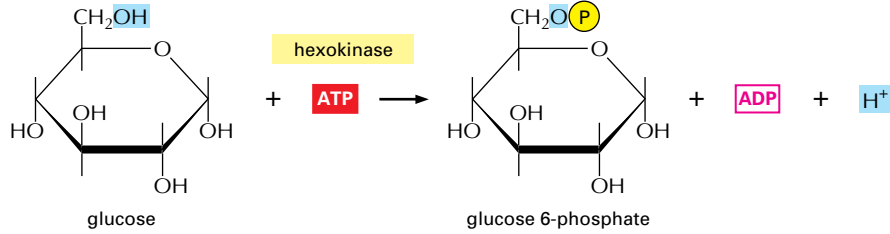
In many cases a sugar sequence is nonrepetitive. Many different molecules are possible. Such complex oligosaccharides are usually linked to proteins or to lipids, as is this oligosaccharide, which is part of a cell-surface molecule that defines a particular blood group.



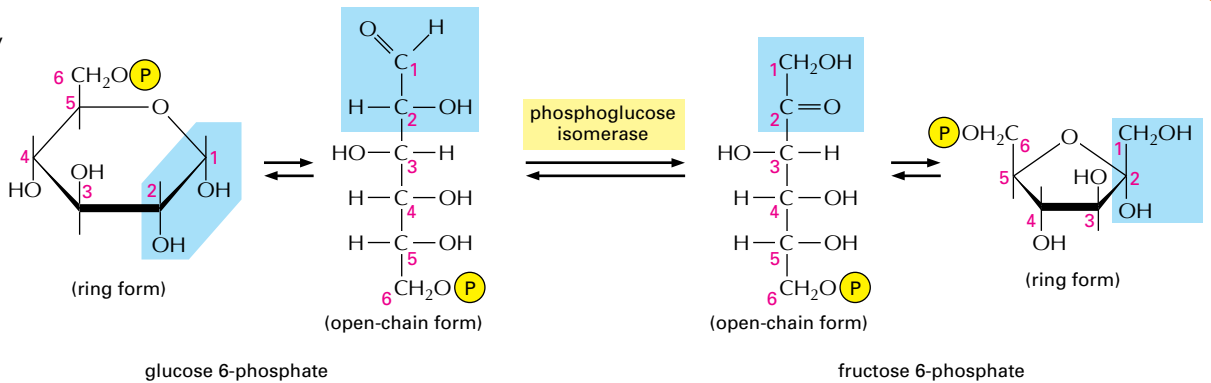
Panel 13-1 Details of the 10 steps of glycolysis

For each step, the part of the molecule that undergoes a change is shadowed in blue, and the name of the enzyme that catalyzes the reaction is in a yellow box.

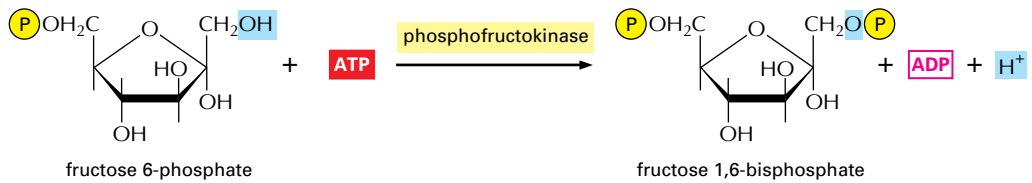
Step 1 Glucose is phosphorylated by ATP to form a sugar phosphate. The negative charge of the phosphate prevents passage of the sugar phosphate through the plasma membrane, trapping glucose inside the cell.



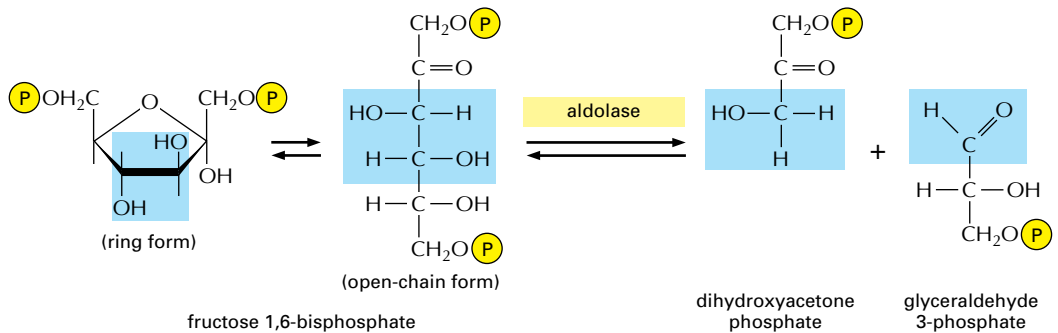
Step 2 A readily reversible rearrangement of the chemical structure (isomerization) moves the carbonyl oxygen from carbon 1 to carbon 2, forming a ketose from an aldose sugar. (See Panel 2-3, pp. 70-71.)



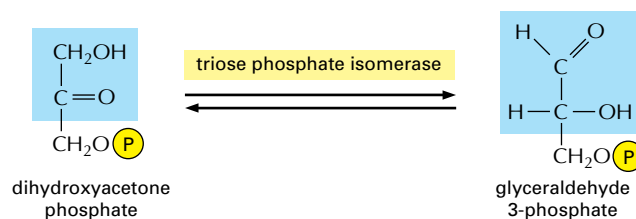
Step 3 The new hydroxyl group on carbon 1 is phosphorylated by ATP, in preparation for the formation of two three-carbon sugar phosphates. The entry of sugars into glycolysis is controlled at this step, through regulation of the enzyme *phosphofructokinase*.



Step 4 The six-carbon sugar is cleaved to produce two three-carbon molecules. Only the glyceraldehyde 3-phosphate can proceed immediately through glycolysis.

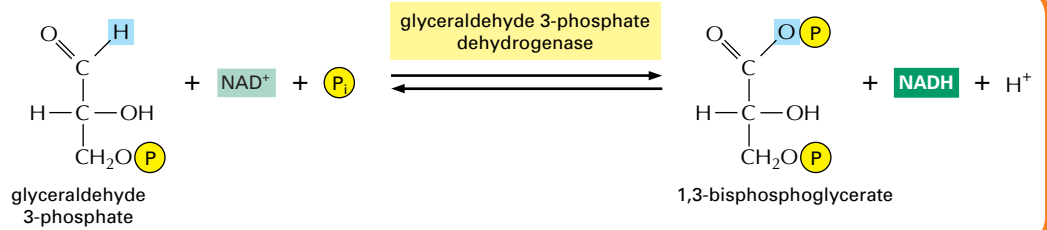


Step 5 The other product of step 4, dihydroxyacetone phosphate, is isomerized to form glyceraldehyde 3-phosphate.

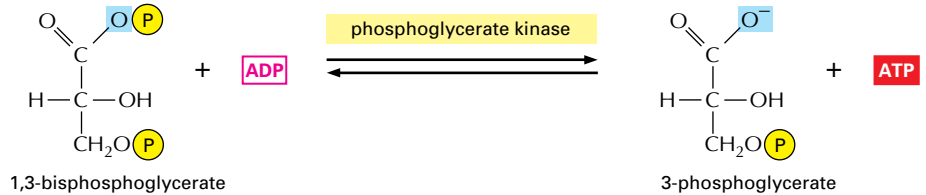


Step 6

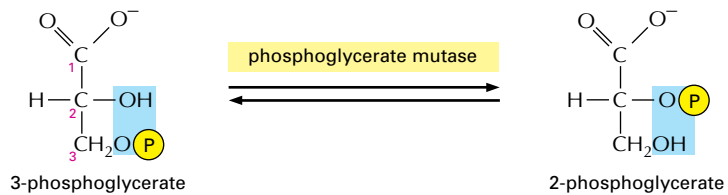
The two molecules of glyceraldehyde 3-phosphate are oxidized. The energy-generation phase of glycolysis begins, as NADH and a new high-energy anhydride linkage to phosphate are formed (see Figure 13-5).

**Step 7**

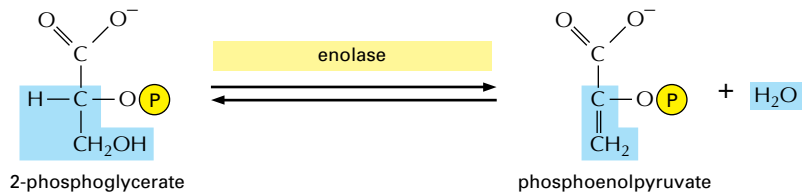
The transfer to ADP of the high-energy phosphate group that was generated in step 6 forms ATP.

**Step 8**

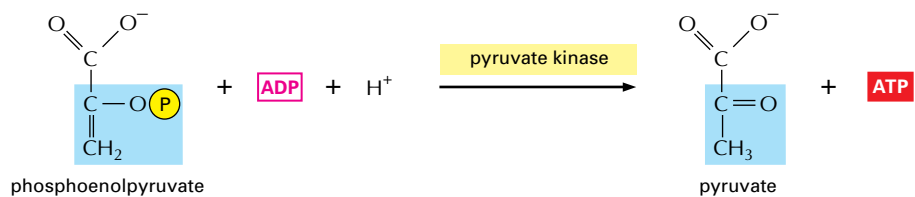
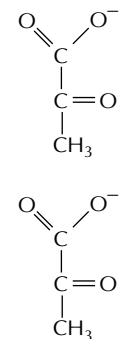
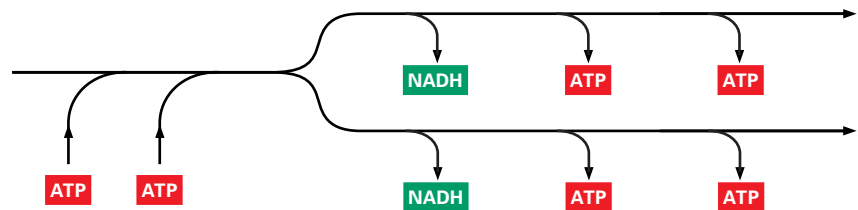
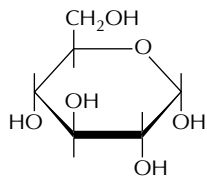
The remaining phosphate ester linkage in 3-phosphoglycerate, which has a relatively low free energy of hydrolysis, is moved from carbon 3 to carbon 2 to form 2-phosphoglycerate.

**Step 9**

The removal of water from 2-phosphoglycerate creates a high-energy enol phosphate linkage.

**Step 10**

The transfer to ADP of the high-energy phosphate group that was generated in step 9 forms ATP, completing glycolysis.

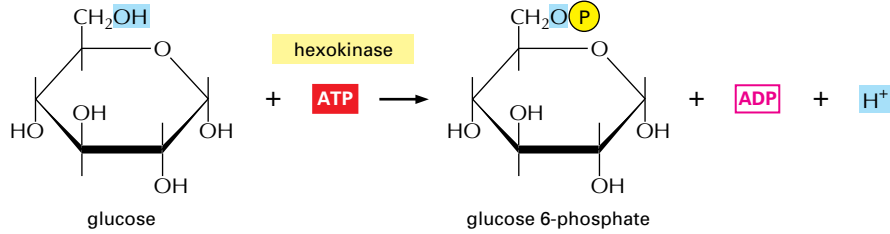
**NET RESULT OF GLYCOLYSIS**

In addition to the pyruvate, the net products are two molecules of ATP and two molecules of NADH.

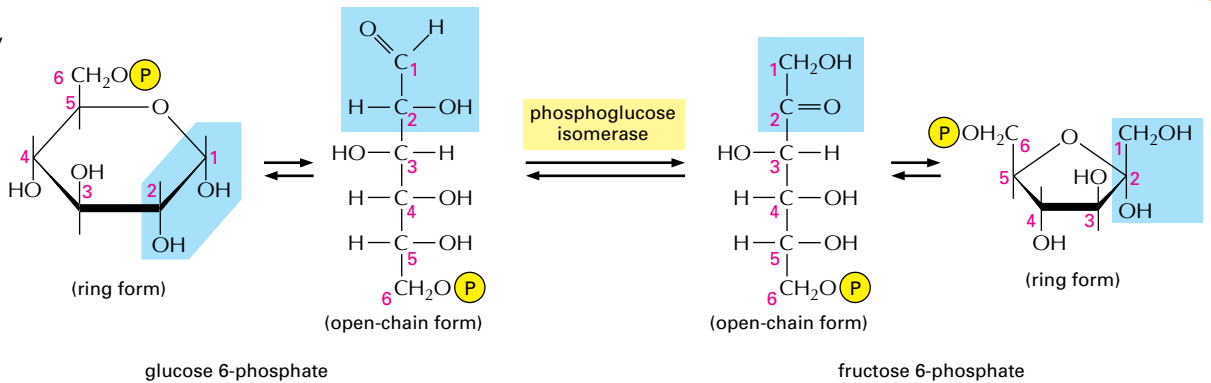
Panel 13-1 Details of the 10 steps of glycolysis

For each step, the part of the molecule that undergoes a change is shadowed in blue, and the name of the enzyme that catalyzes the reaction is in a yellow box.

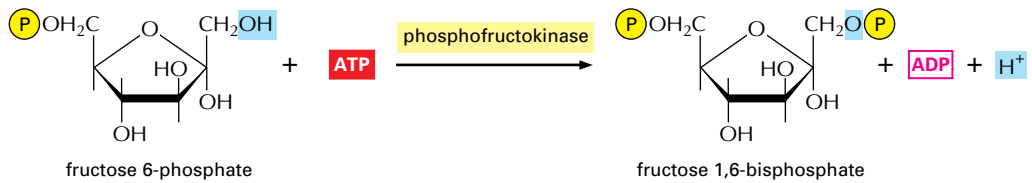
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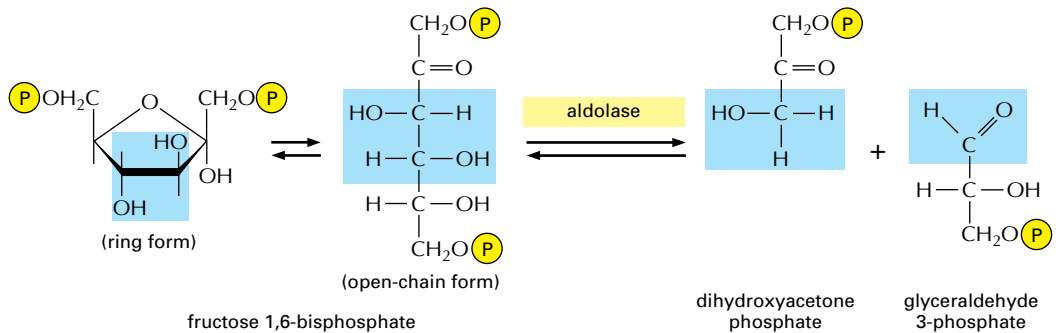
Step 2 A readily reversible rearrangement of the chemical structure (isomerization) moves the carbonyl oxygen from carbon 1 to carbon 2, forming a ketose from an aldose sugar. (See Panel 2-3, pp. 70-71.)



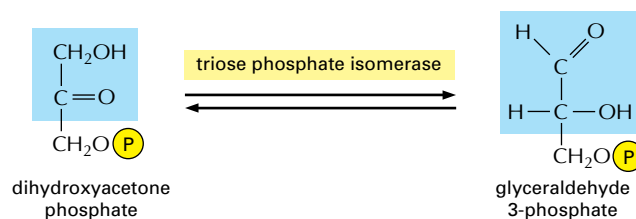
Step 3 The new hydroxyl group on carbon 1 is phosphorylated by ATP, in preparation for the formation of two three-carbon sugar phosphates. The entry of sugars into glycolysis is controlled at this step, through regulation of the enzyme *phosphofructokinase*.



Step 4 The six-carbon sugar is cleaved to produce two three-carbon molecules. Only the glyceraldehyde 3-phosphate can proceed immediately through glycolysis.

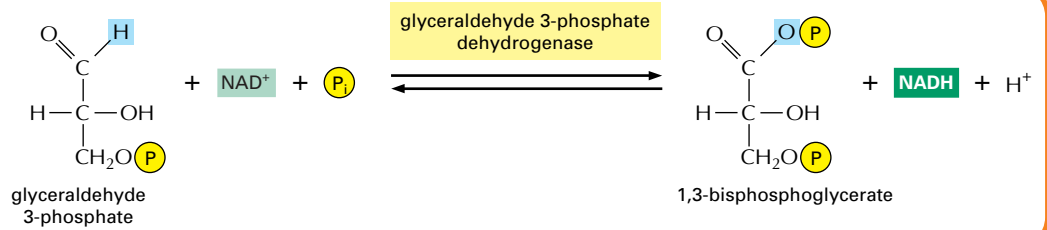


Step 5 The other product of step 4, dihydroxyacetone phosphate, is isomerized to form glyceraldehyde 3-phosphate.

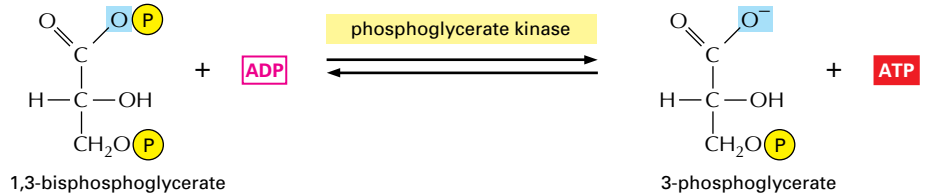


Step 6

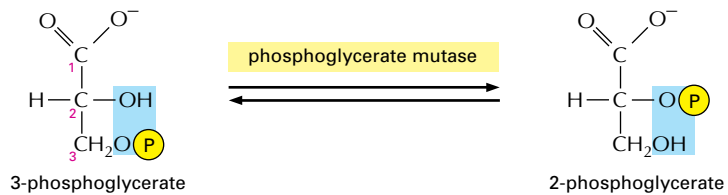
The two molecules of glyceraldehyde 3-phosphate are oxidized. The energy-generation phase of glycolysis begins, as NADH and a new high-energy anhydride linkage to phosphate are formed (see Figure 13-5).

**Step 7**

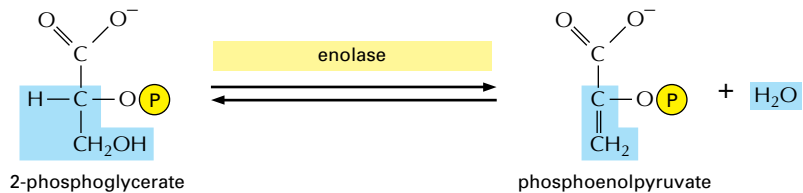
The transfer to ADP of the high-energy phosphate group that was generated in step 6 forms ATP.

**Step 8**

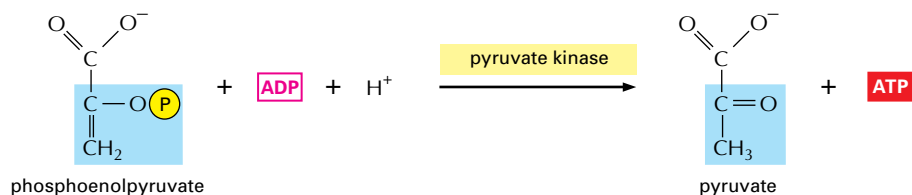
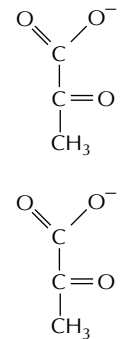
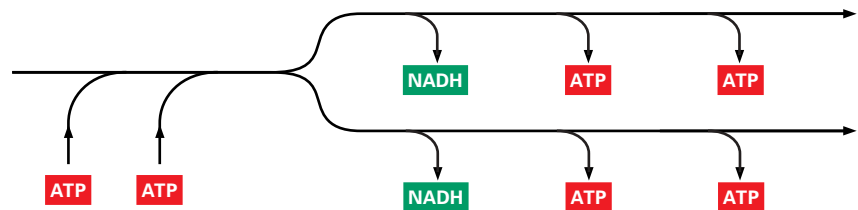
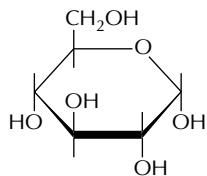
The remaining phosphate ester linkage in 3-phosphoglycerate, which has a relatively low free energy of hydrolysis, is moved from carbon 3 to carbon 2 to form 2-phosphoglycerate.

**Step 9**

The removal of water from 2-phosphoglycerate creates a high-energy enol phosphate linkage.

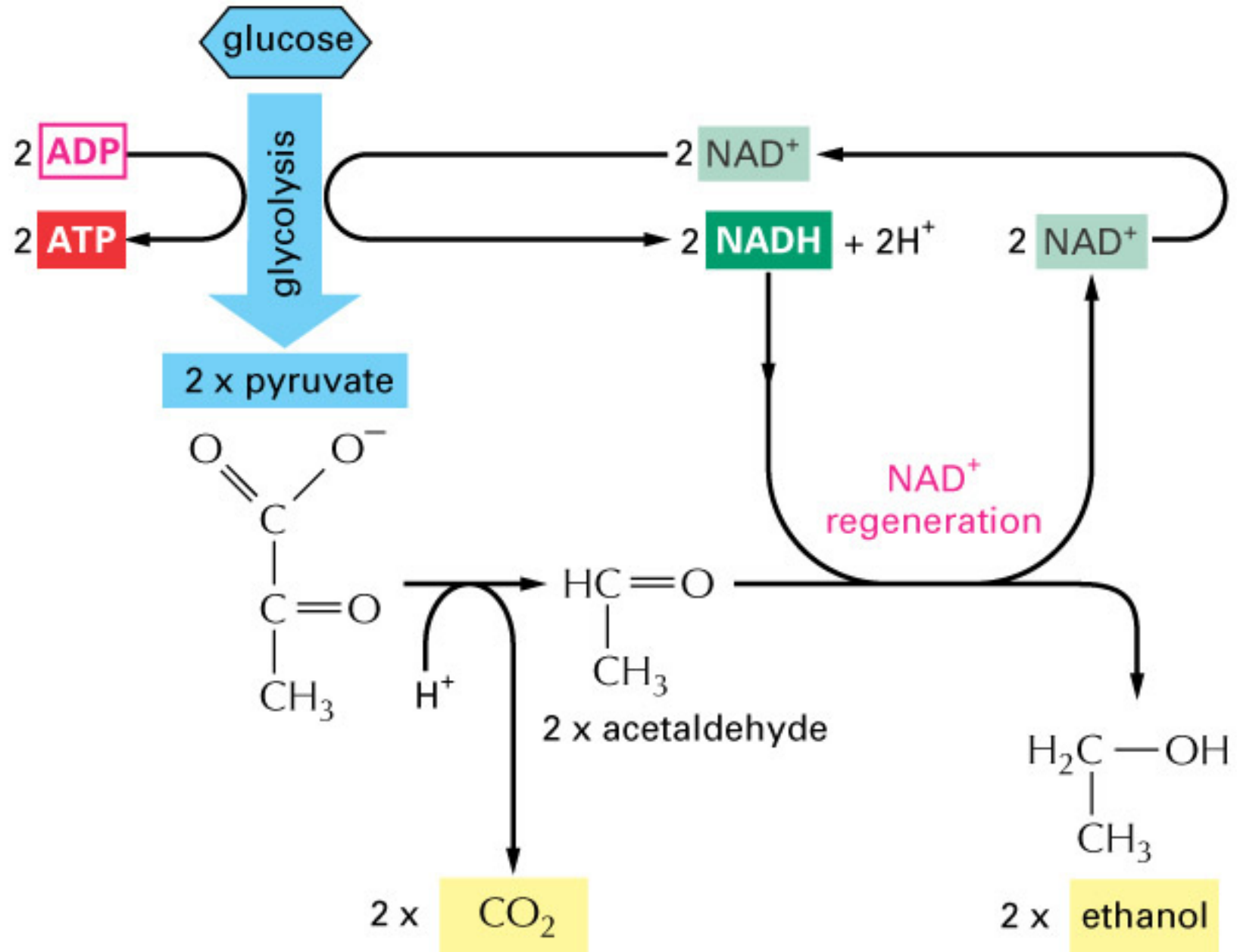
**Step 10**

The transfer to ADP of the high-energy phosphate group that was generated in step 9 forms ATP, completing glycolysis.

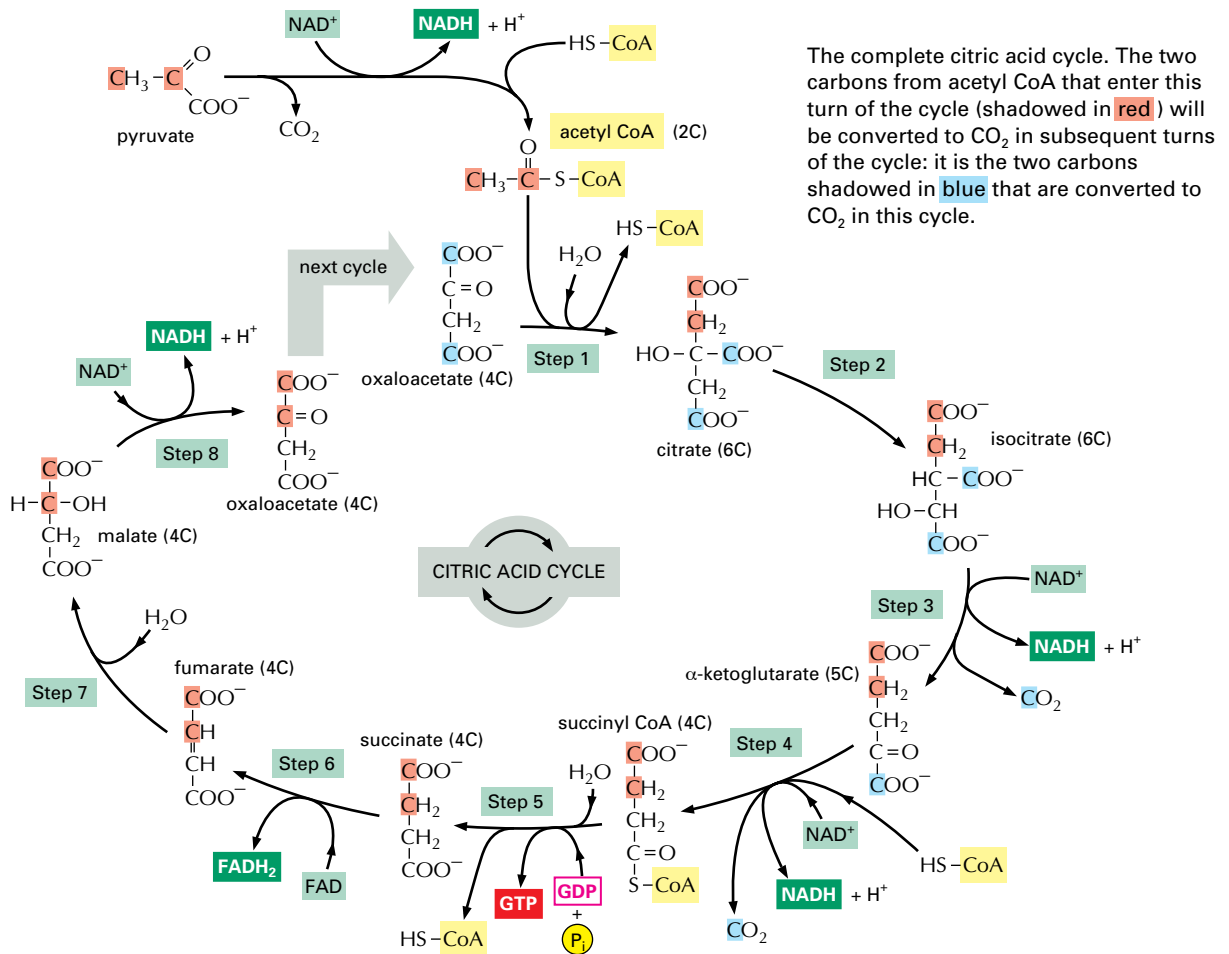
**NET RESULT OF GLYCOLYSIS**

In addition to the pyruvate, the net products are two molecules of ATP and two molecules of NADH.

(B) FERMENTATION LEADING TO EXCRETION OF ALCOHOL AND CO₂



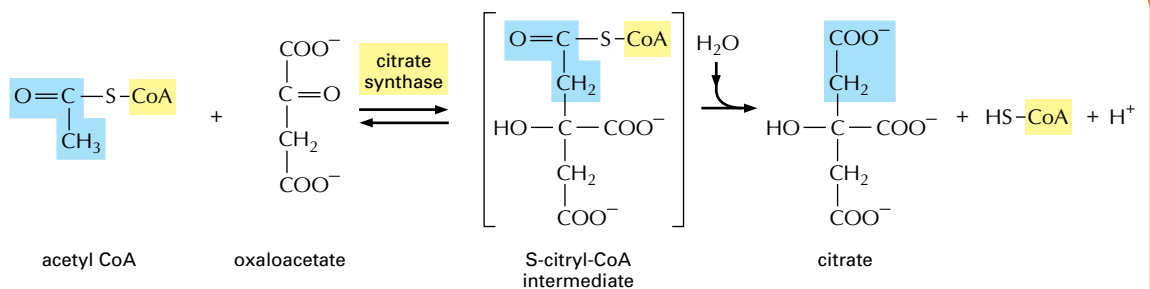
Panel 13-2 The complete citric acid cycle



Details of the eight steps are shown below. For each step, the part of the molecule that undergoes a change is shadowed in blue, and the name of the enzyme that catalyzes the reaction is in a yellow box.

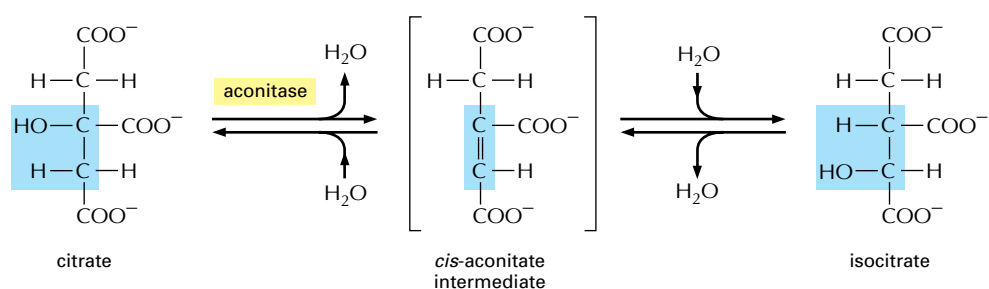
Step 1

After the enzyme removes a proton from the CH₃ group on acetyl CoA, the negatively charged CH₂⁻ forms a bond to a carbonyl carbon of oxaloacetate. The subsequent loss by hydrolysis of the coenzyme A (CoA) drives the reaction strongly forward.



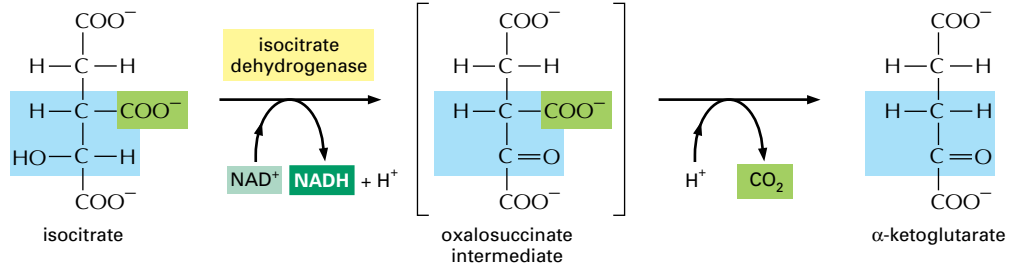
Step 2

An isomerization reaction, in which water is first removed and then added back, moves the hydroxyl group from one carbon atom to its neighbor.

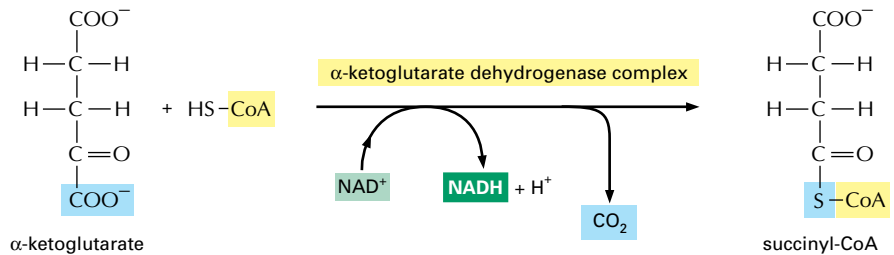


Step 3

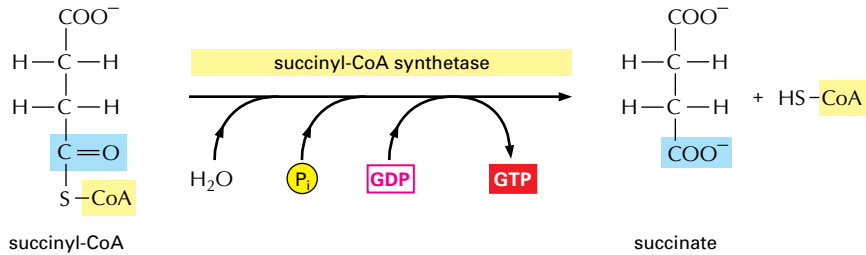
In the first of four oxidation steps in the cycle, the carbon carrying the hydroxyl group is converted to a carbonyl group. The immediate product is unstable, losing CO_2 while still bound to the enzyme.

**Step 4**

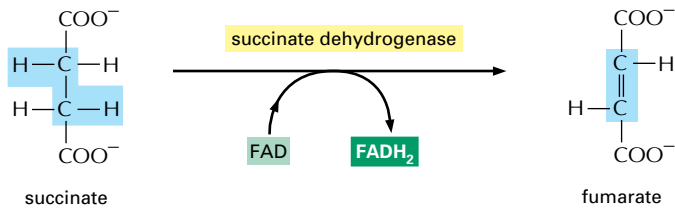
The α -ketoglutarate dehydrogenase complex closely resembles the large enzyme complex that converts pyruvate to acetyl CoA (pyruvate dehydrogenase). It likewise catalyzes an oxidation that produces NADH , CO_2 , and a high-energy thioester bond to coenzyme A (CoA).

**Step 5**

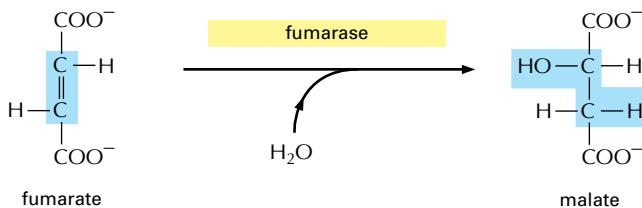
A phosphate molecule from solution displaces the CoA, forming a high-energy phosphate linkage to succinate. This phosphate is then passed to GDP to form GTP. (In bacteria and plants, ATP is formed instead.)

**Step 6**

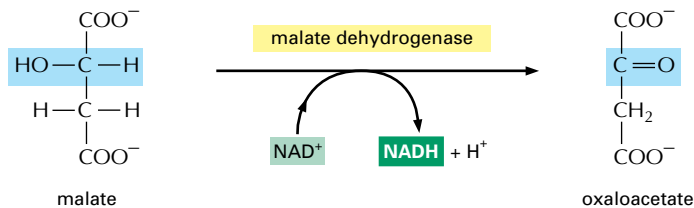
In the third oxidation step in the cycle, FAD removes two hydrogen atoms from succinate.

**Step 7**

The addition of water to fumarate places a hydroxyl group next to a carbonyl carbon.

**Step 8**

In the last of four oxidation steps in the cycle, the carbon carrying the hydroxyl group is converted to a carbonyl group, regenerating the oxaloacetate needed for step 1.



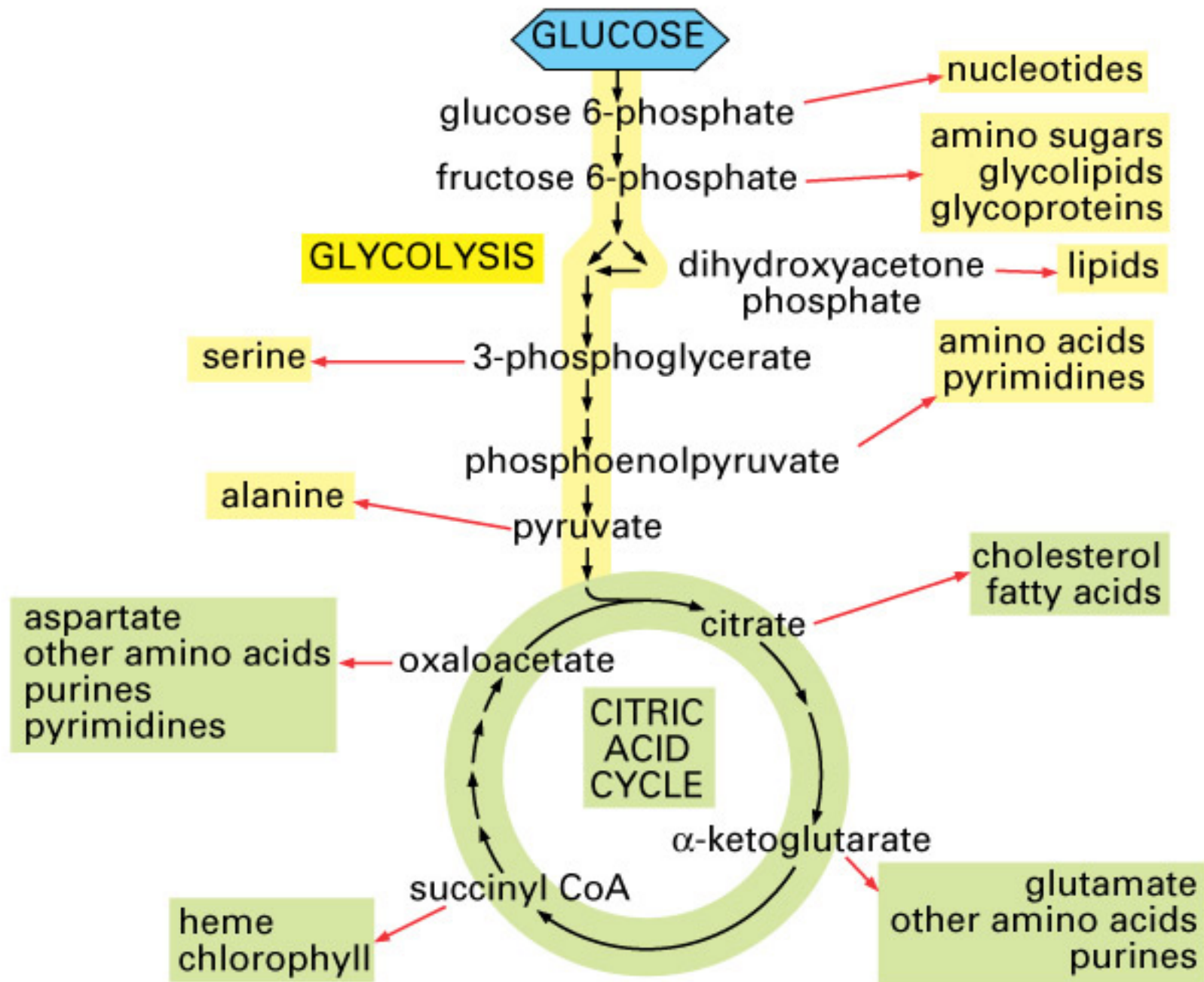


Figure 13-23 Essential Cell Biology, 2/e. (© 2004 Garland Science)