CHAPTER ~~19~~ 16: GLYCOLYSIS

Glycolysis: From the greek word "glykys," meaning "sweet" and "lysis" meaning "splitting"

- **A sequence of enzyme- catalyzed reactions that convert a molecule of glucose into two molecules of pyruvate (a three- carbon compound) with the production of some ATP and NADH**

History of Glycolysis

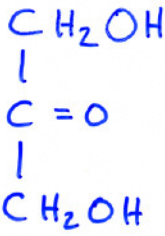
- **1897: Hans and Eduard Buchner discovered that sucrose is fermented into alcohol by yeast extract**

- **1860: Louis Pasteur discovered fermentation**

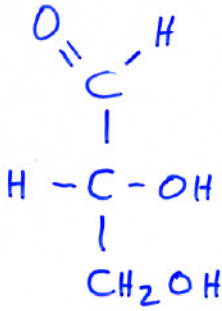
- **1905: Arthur Harden and William Young isolated a key component of glycolysis (fructose 1, 6- bisphosphate)**

- **1940's: Elucidation of the complete glycolytic pathway by Embden, Meyerhor, Neuberg, Parnas, Warburg, Gerty Cori, and Carl Cori**

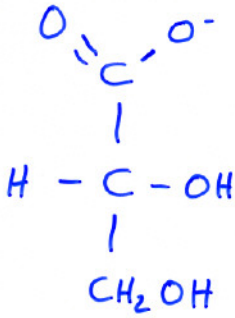
Key structures



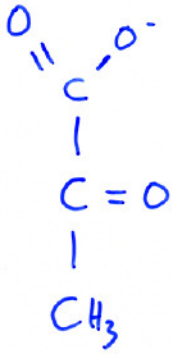
dihydroxyacetone



glyceraldehyde

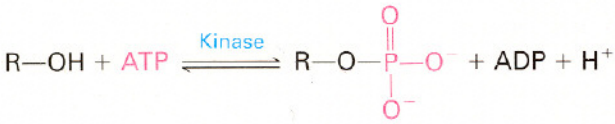


glycerate



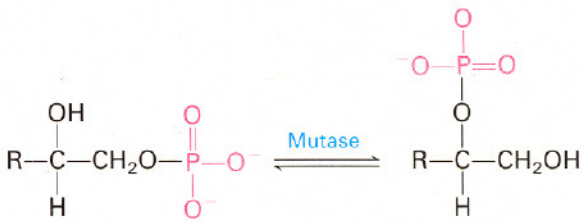
pyruvate

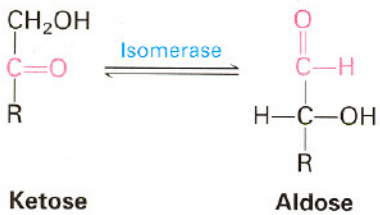
Key reactions



Phosphoryl transfer

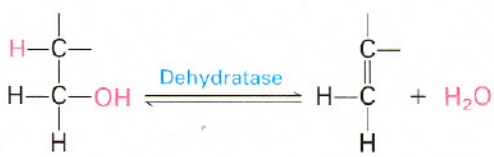
Phosphoryl shift

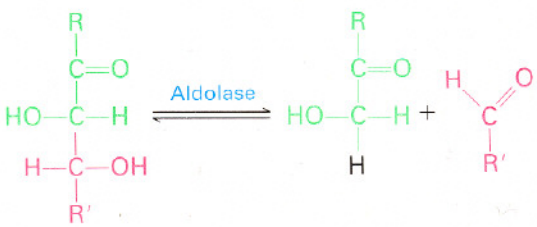




Isomerization

Dehydration





Aldol cleavage

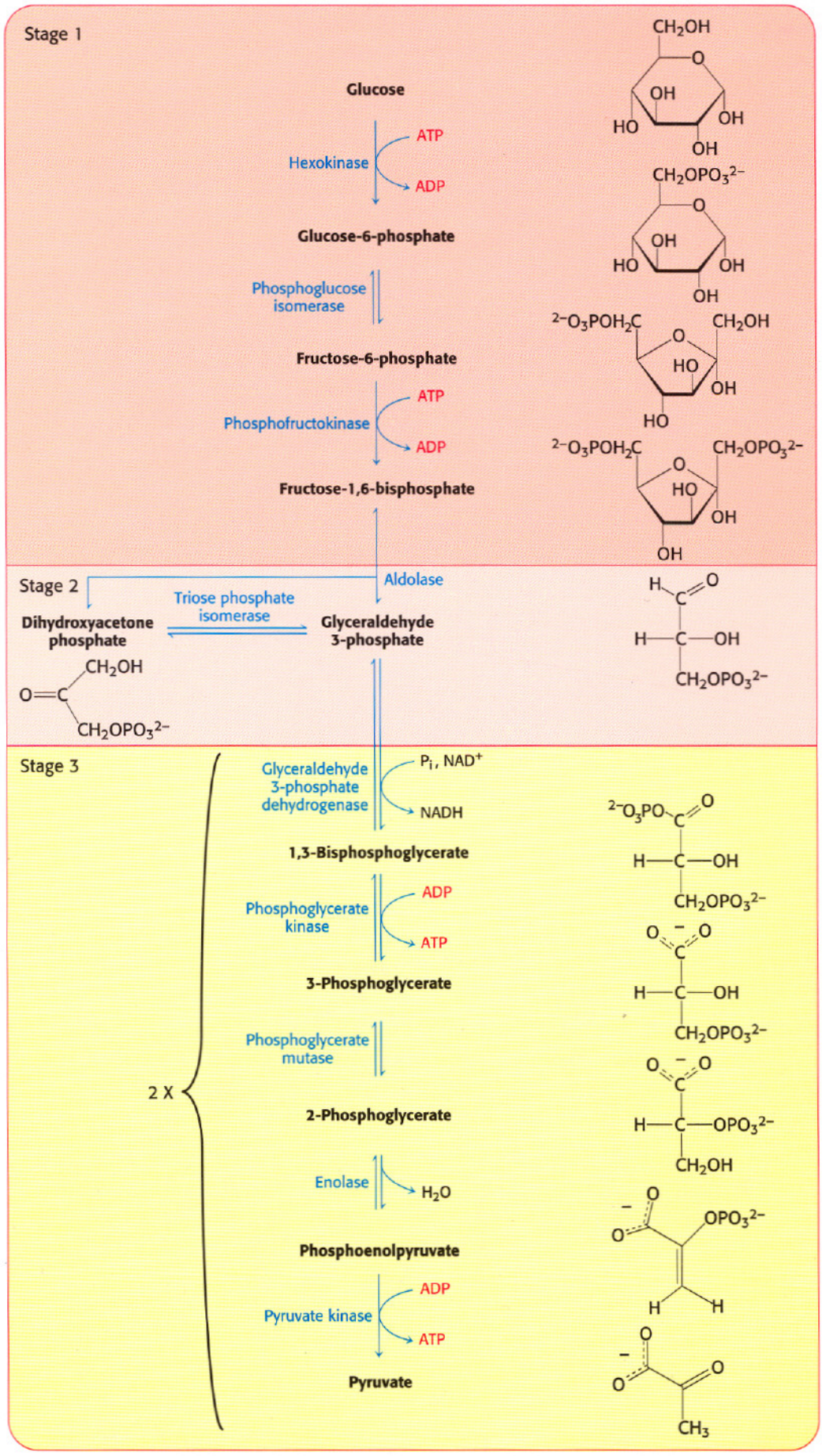
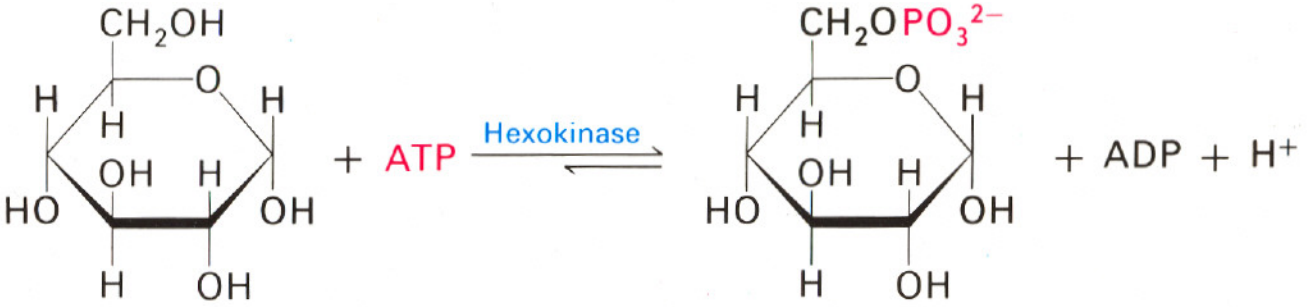


Figure 16-3
Stryer, Tymoczko, & Berg, BIOCHEMISTRY, Fifth Edition.

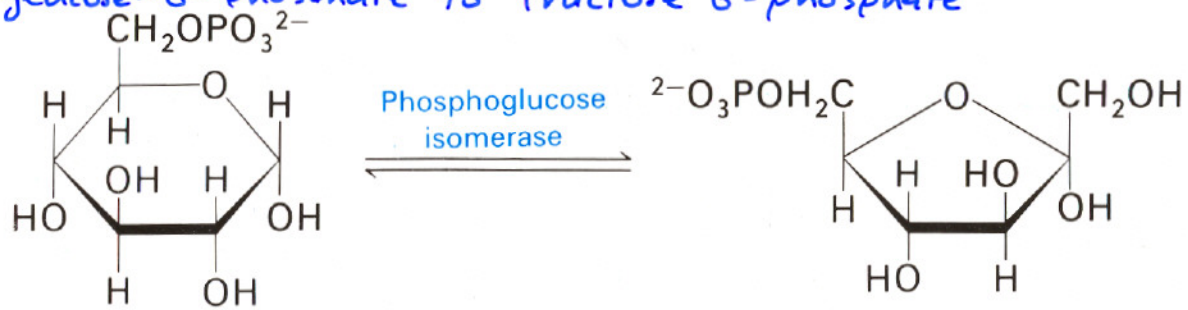
1. Phosphorylation of glucose



Glucose **Glucose 6-phosphate**

$\Delta G^{\circ\prime} = -4.0$ kcal/mol

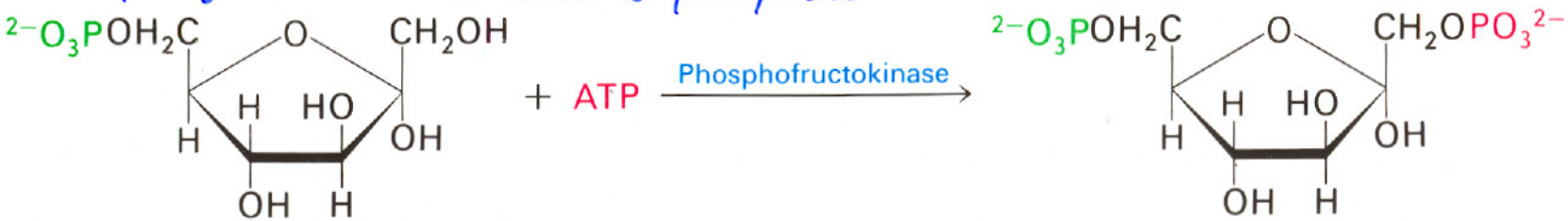
2. Conversion of glucose-6-phosphate to fructose 6-phosphate



Glucose 6-phosphate **Fructose 6-phosphate**

$\Delta G^{\circ\prime} = +0.4$ kcal/mol

3. Phosphorylation of fructose 6-phosphate



Fructose 6-phosphate **Fructose 1,6-bisphosphate**

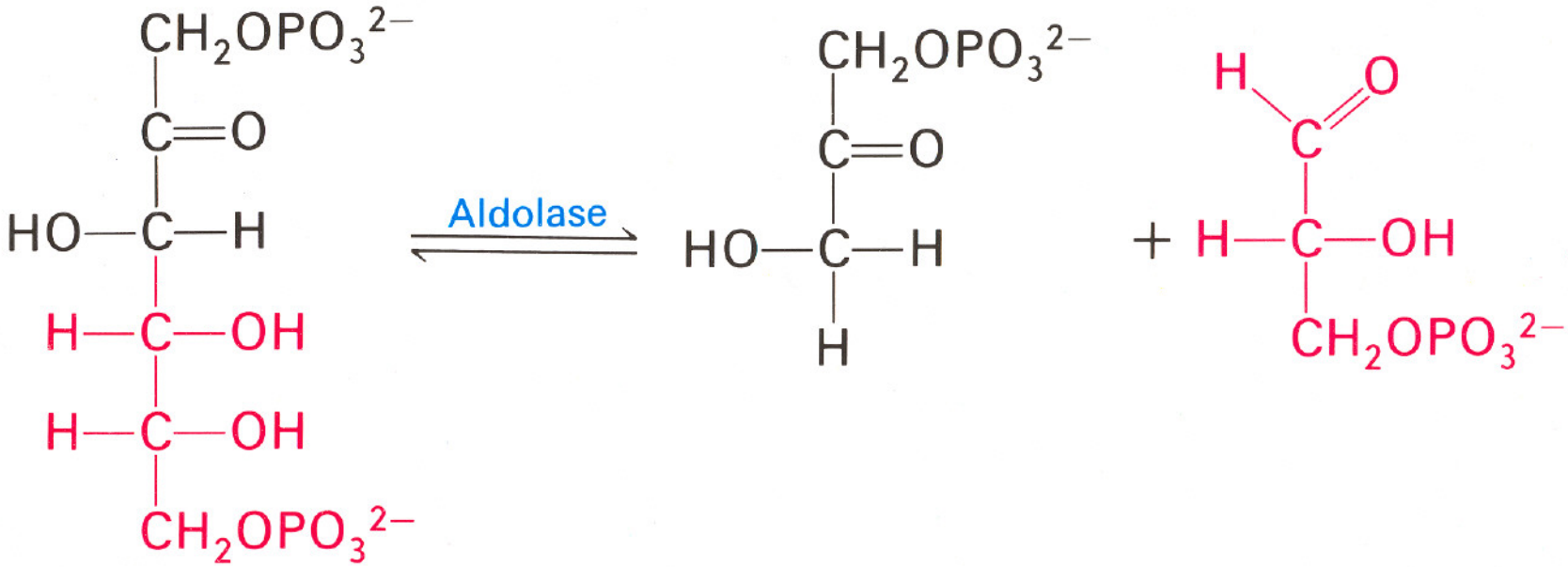
$\Delta G^{\circ\prime} = -3.4$ kcal/mol

Assorted figures from pages 486 and 487

Stryer: *Biochemistry*, Fourth Edition

4. Cleavage of fructose 1,6-bisphosphate

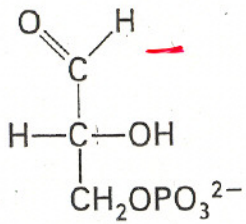
$\Delta G^{\circ\prime} = +5.7$ kcal/mol



Fructose 1,6-bisphosphate | **Dihydroxyacetone phosphate** | **Glyceraldehyde 3-phosphate**

Bottom figure, page 487

6. Oxidation of glyceraldehyde 3-phosphate



Glyceraldehyde 3-phosphate

+

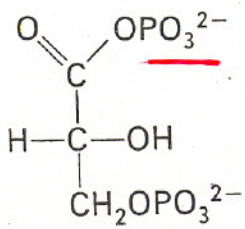
NAD^+

+

P_i

Glyceraldehyde 3-phosphate dehydrogenase

$\Delta G^{\circ\prime} = +1.5$ kcal/mol



1,3-Bisphosphoglycerate (1,3-BPG)

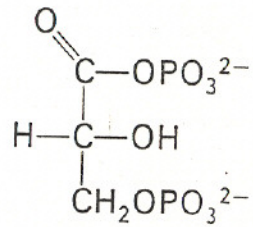
+

NADH

+

H^+

7. Phosphoryl transfer from 1,3-bisphosphoglycerate to ADP



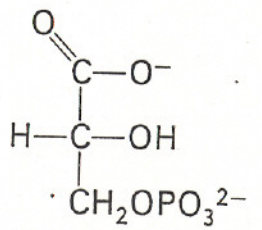
1,3-Bisphosphoglycerate

+

ADP

Phosphoglycerate kinase

$\Delta G^{\circ\prime} = -4.5$ kcal/

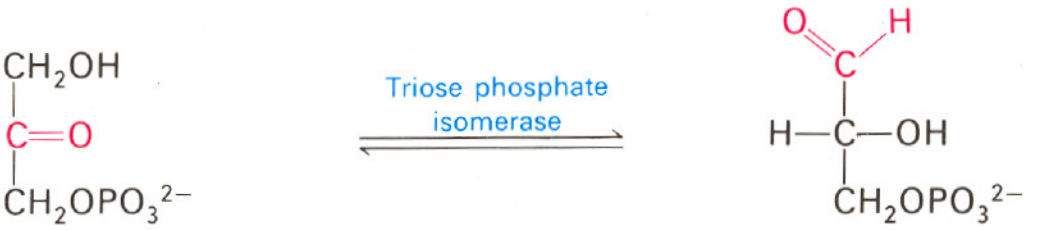


3-Phosphoglycerate

+

ATP

5. Interconversion of the triose phosphates



Dihydroxyacetone phosphate
(A ketose)

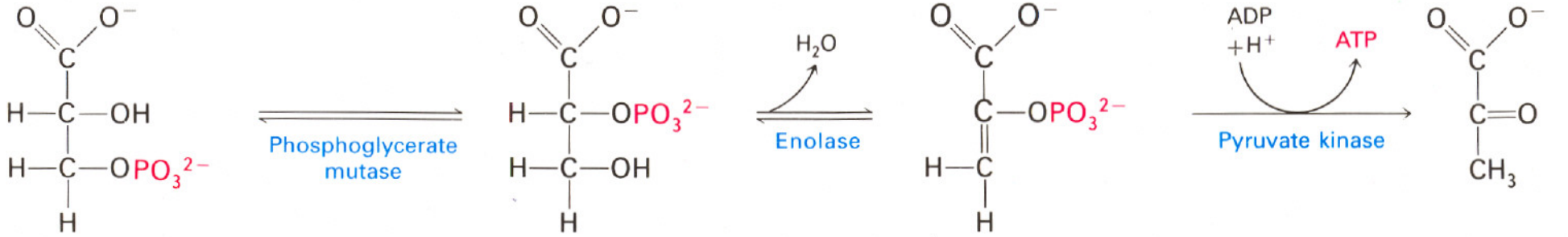
Glyceraldehyde 3-phosphate
(An aldose)

$\Delta G^{\circ\prime} = +1.8$ kcal/mol

8. Conversion of 3-phosphoglycerate to 2-phosphoglycerate

9. Dehydration of 2-phosphoglycerate to phosphoenolpyruvate

10. Transfer of the ~P group to ADP



3-Phosphoglycerate — **2-Phosphoglycerate** — **Phosphoenolpyruvate** — **Pyruvate**

$\Delta G^{\circ\prime} = +1.1$ kcal/mol

$\Delta G^{\circ\prime} = +0.4$ kcal/mol

$\Delta G^{\circ\prime} = -7.5$ kcal/mol

Glycolytic reactions, pages 488, 489

Stryer: *Biochemistry*, Fourth Edition

The net reaction in the transformation of glucose into pyruvate is

$$\text{Glucose} + 2\,P_i + 2\,ADP + 2\,NAD^+ \longrightarrow 2\ \text{pyruvate} + 2\,ATP + 2\,NADH + 2\,H^+ + 2\,H_2O$$

Table 19-1
Consumption and generation of ATP in glycolysis

Reaction	*ATP change per glucose*
Glucose ⟶ glucose 6-phosphate	−1
Fructose 6-phosphate ⟶ fructose 1,6-bisphosphate	−1
2 1,3-Bisphosphoglycerate ⟶ 2 3-phosphoglycerate	+2
2 Phosphoenolpyruvate ⟶ 2 pyruvate	+2
Net	+2

Reactions of glycolysis

Step	*Reaction*	*Enzyme*	*Type**	$\Delta G^{\circ\prime}$	ΔG
1	Glucose + ATP $\longrightarrow$ glucose 6-phosphate + ADP + H^+	Hexokinase	a	−4.0	−8.0
2	Glucose 6-phosphate $\rightleftharpoons$ fructose 6-phosphate	Phosphoglucose isomerase	c	+0.4	−0.6
3	Fructose 6-phosphate + ATP $\longrightarrow$ fructose 1,6-bisphosphate + ADP + H^+	Phosphofructokinase	a	−3.4	−5.3
4	Fructose 1,6-bisphosphate $\rightleftharpoons$ dihydroxyacetone phosphate + glyceraldehyde 3-phosphate	Aldolase	e	+5.7	−0.3
5	Dihydroxyacetone phosphate $\rightleftharpoons$ glyceraldehyde 3-phosphate	Triose phosphate isomerase	c	+1.8	+0.6
6	Glyceraldehyde 3-phosphate + P_i + NAD^+ $\rightleftharpoons$ 1,3-bisphosphoglycerate + NADH + H^+	Glyceraldehyde 3-phosphate dehydrogenase	f	+1.5	−0.4
7	1,3-Bisphosphoglycerate + ADP $\rightleftharpoons$ 3-phosphoglycerate + ATP	Phosphoglycerate kinase	a	−4.5	+0.3
8	3-Phosphoglycerate $\rightleftharpoons$ 2-phosphoglycerate	Phosphoglyceratmutase	b	+1.1	+0.2
9	2-Phosphoglycerate $\rightleftharpoons$ phosphoenolpyruvate + H_2O	Enolase	d	+0.4	−0.8
10	Phosphoenolpyruvate + ADP + H^+ $\longrightarrow$ pyruvate + ATP	Pyruvate kinase	a	−7.5	−4.0

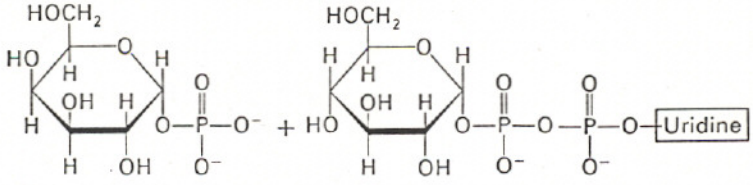
*Reaction type: (a) phosphoryl transfer; (b) phosphoryl shift; (c) isomerization; (d) dehydration; (e) aldol cleavage; (f) phosphorylation coupled to oxidation.

Note: $\Delta G^{\circ\prime}$ and ΔG are expressed in kcal/mol. ΔG, the actual free-energy change, has been calculated from $\Delta G^{\circ\prime}$ and known concentrations of reactants under typical physiologic conditions. Glycolysis can proceed only if the ΔG values of all reactions are negative. The small positive ΔG values of three of the above reactions indicate that the concentrations of metabolites in vivo in cells undergoing glycolysis are not precisely known.

Stryer: *Biochemistry,* Fourth Edition

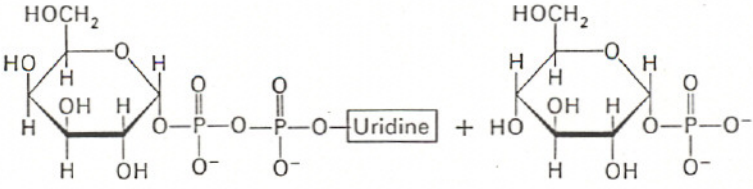
galactokinase

Galactose + ATP ⟶ galactose 1-phosphate + ADP + H^+



Galactose 1-phosphate UDP–glucose

‖ UDP-galactose 4-epimerase



UDP–galactose Glucose 1-phosphate

The sum of the reaction:

Galactose + ATP ⟶ glucose 1-phosphate + ADP + H^+