CELLULAR RESPIRATION

Part 1: Glycolysis & Fermentation

Sources of Stored Energy in the human body

- Glycogen (carbohydrates)
  - Recall: plants store carbohydrates as starch
- Fats (lipid)
- Muscle tissue (protein)

- Your body harnesses stored energy to do cellular work in a particular order

Sources of Energy

Carbohydrates

- glucose most usable source of energy
- cells turn to other fuels only if glucose supplies have been depleted

Lipids (fat)

- when glucose is depleted, this becomes the source of energy

Sources of Energy

Proteins

- final resort when no forms of energy are available
- cell is breaking down its own structures to obtain energy (not good)

http://img7.imageshack.us/img7/9499/OlsenBones.jpg

Thought Questions

- Why do football players eat a huge bowl of pasta before their game?
- What do you think is the scientific reasoning behind low carb / high protein diets?
- What is happening with metabolism in individuals with anorexia?

Goals of Cellular Respiration

- Purpose: to convert stored energy in organic fuel to ATP
- Overall goal: to transfer the energy in the bonds of organic molecules (e.g. glucose) to a usable form of energy recognized by all cells (ATP)
- Overall reaction:

glucose + oxygen → carbon dioxide + water + energy

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$

36 ADP + 36 P → 36 ATP (or 38 ADP + 38 P → 38 ATP)

Goals of Cellular Respiration

$$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$$

$$36\ ADP + 36\ P \rightarrow 36\ ATP\ (or\ 38)$$

- Details:
  - To break 6-carbon glucose down and release 6 molecules of CO_2
  - Move glucose electrons to O_2, and combine with H^+ ions to form 6 molecules of H_2O
  - Collect energy in the form of ATP

Types of Cellular Respiration

- In the presence of oxygen: aerobic
  - Glycolysis
  - Pyruvate oxidation, Krebs cycle
  - ETC, Oxidative phosphorylation
- In the absence of oxygen: anaerobic
  - Glycolysis
  - alcoholic fermentation (yeast)
  - lactic acid fermentation (humans)

Four Major Stages of Cellular Respiration

- Glycolysis
  - Breaks down glucose into two molecules of pyruvate

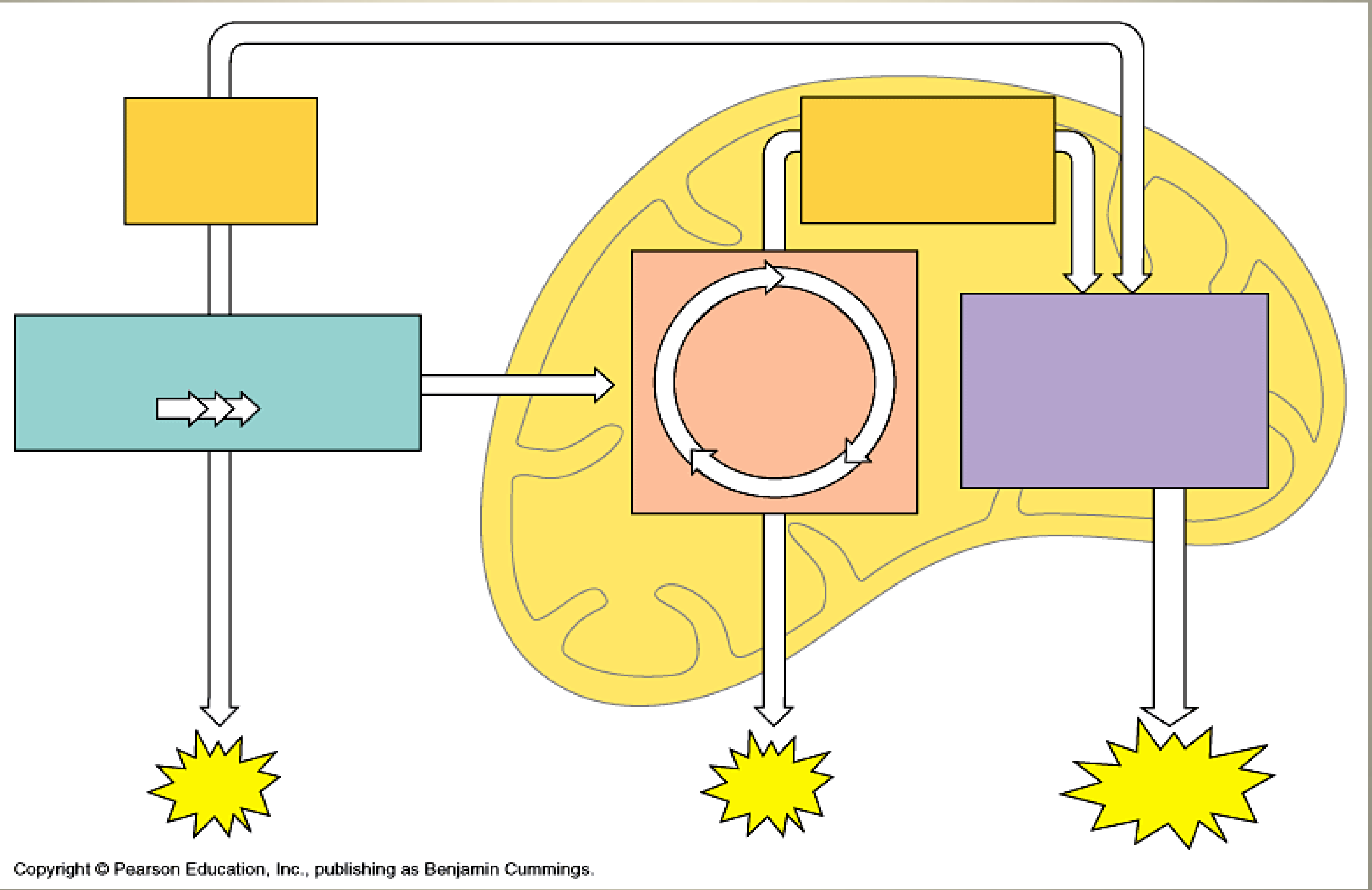
does not require O_2 occurs in the cytoplasm

- Oxidative Decarboxylation
  - Pyruvate oxidation
- Krebs / Citric acid cycle
  - Completes the breakdown of glucose
- Electron Transport Chain and Oxidative phosphorylation

  Generates ATP

require O_2 occurs in the mitochondria

An overview of cellular respiration



An overview of cellular respiration

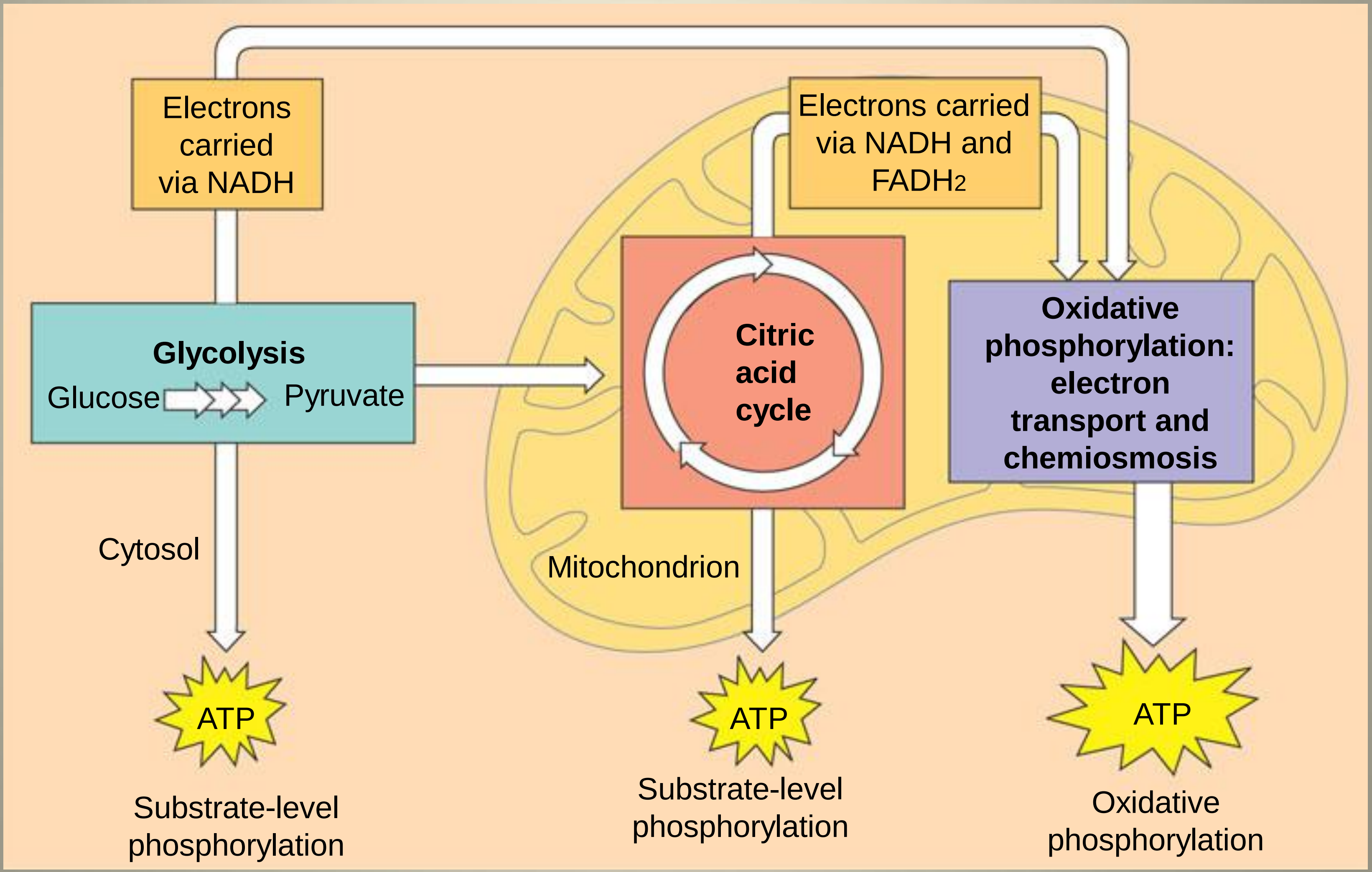


Figure 9.6

Glycolysis

- Glyco … lysis
  - "splitting of sugar"
  - From 6-C sugar to two 3-C sugar
- Breaks down glucose (6C) into pyruvate (3C)
- Occurs in the cytoplasm of the cell

Classes of Enzymes

Enzyme	Reaction	Description
Kinase	Phosphorylation	Phosphate group is removed (often from ATP) and attached to another molecule
Dehydrogenase	Redox	Electron transfer usually from organic fuel to the electron carriers (NAD+ and FAD)
Decarboxylase	Decarboxylation	Removal of carbon usually in the form of CO_2. CO_2 released as a waste product.
Isomerase	Isomerization	Producing isomers. Also known as mutase.
Lyase	Cleavage	Splitting of a molecule or removal of a part of the molecule.
Synthase	Synthesis	Forming a molecule by combining 2 or more molecules.
Hydrase	Hydration	Addition of water to a molecule

Activity

- Order the molecules in glycolysis based on each molecule's structure
- Hint:
  - 6C compound will split into two 3C compounds that are isomers of each other
  - Only one of the two 3C compounds will continue in the reaction
- Once your teacher has checked your answer, then hypothesize the class of enzyme that catalyzes each step of the reaction

Cellular Respiration: What to know!

- What is the purpose of each step?
- What TYPE of reaction is happening?
- What TYPE of enzyme is used? (not the specific enzyme name)
- Energy distribution at each step.

Important molecules in glycolysis

- Glucose
- DHAP
- G3P
- PEP
- Pyruvate
- ATP
- NADH

Two major phases in Glycolysis

- Energy investment phase
- Energy payoff phase

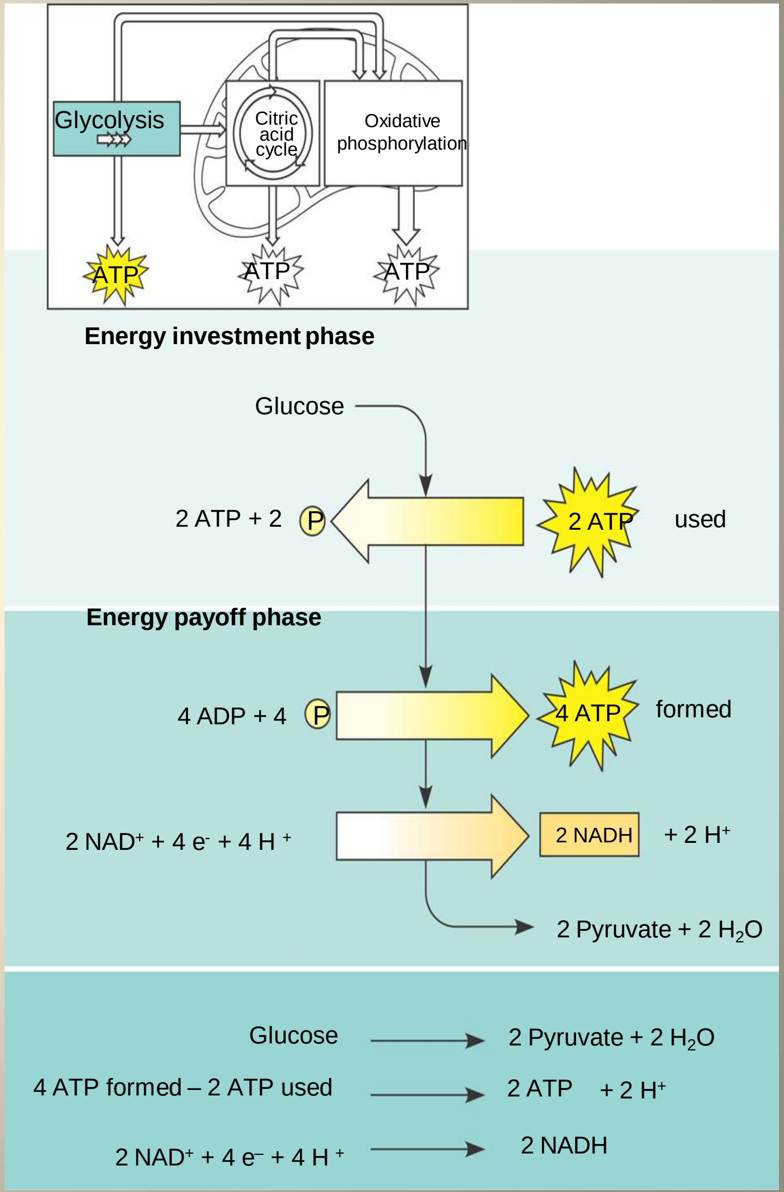


Figure 9.8

Energy Investment Phase

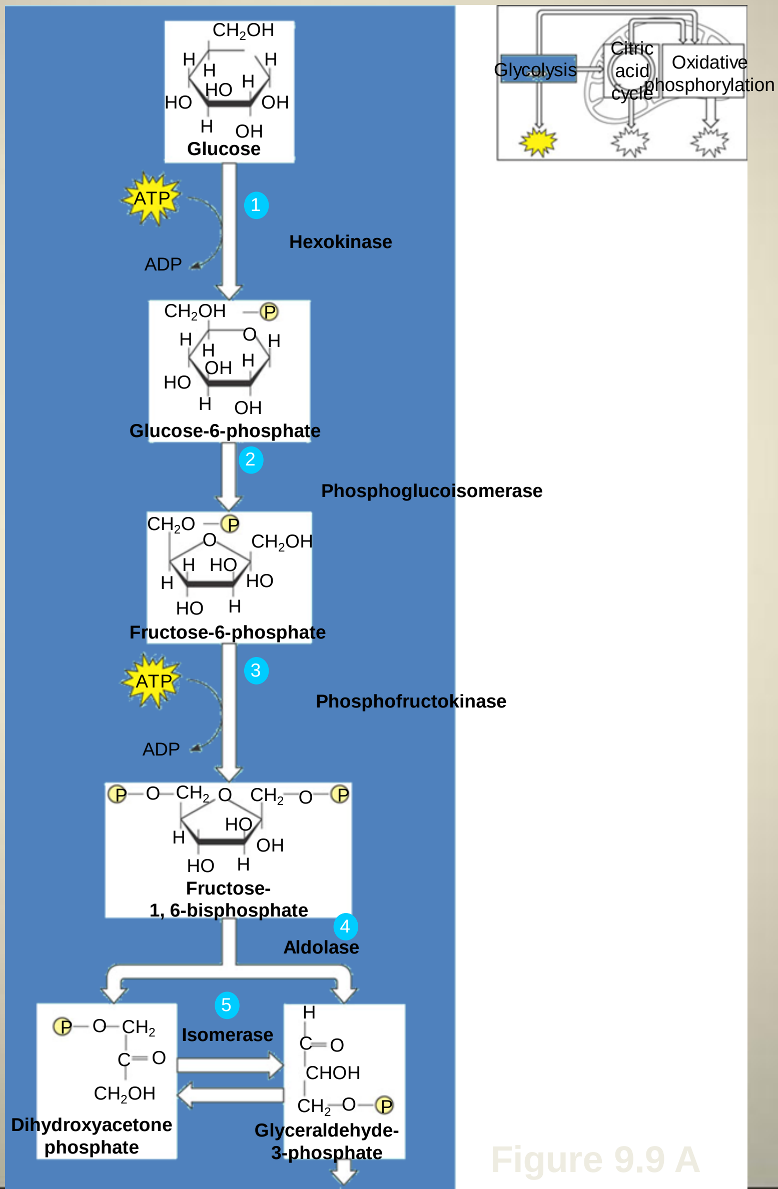
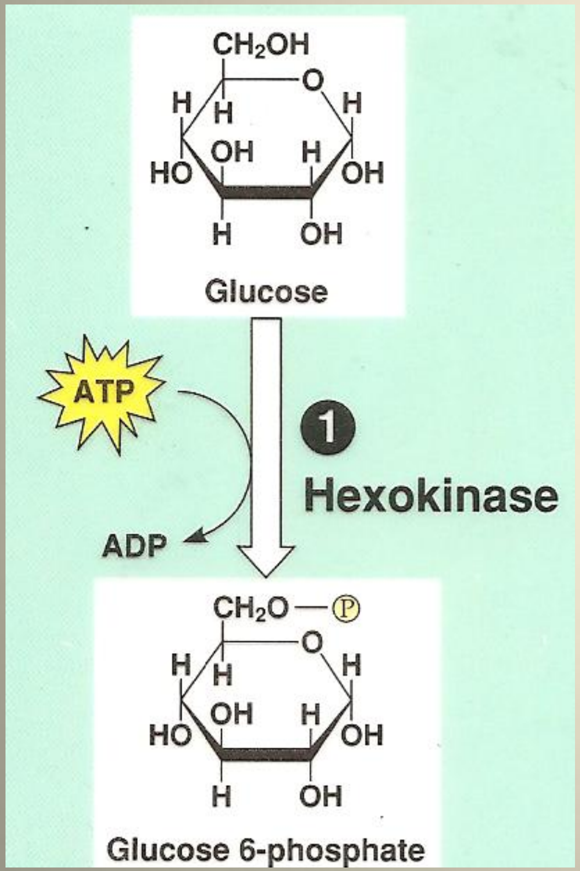


Figure 9.9 A

Glycolysis: Step by Step

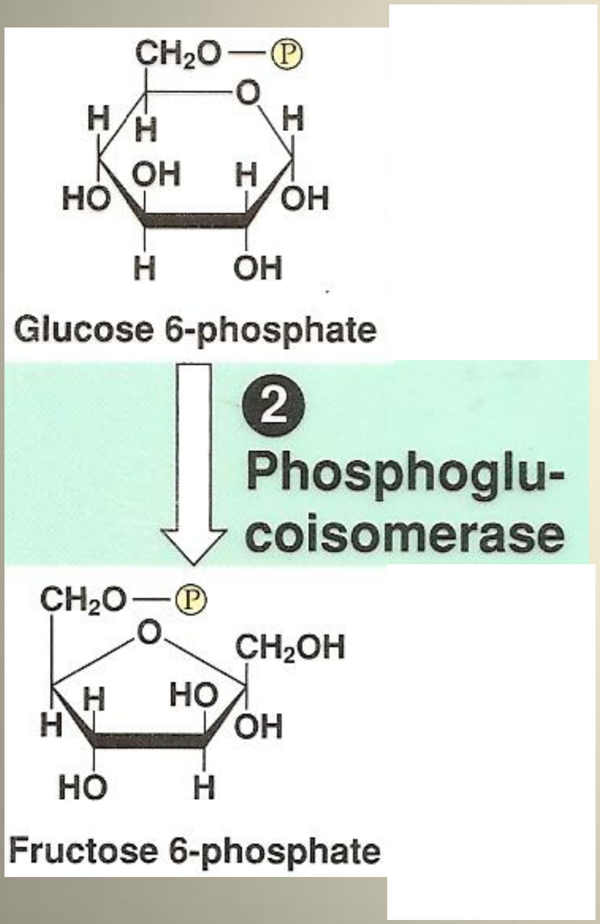


Step 1:

- carbon 6 phosphorylated using ATP to prevent glucose from leaving the cell

- reaction type: phosphorylation
- enzyme: kinase
- energy: absorbed

Glycolysis: Step by Step

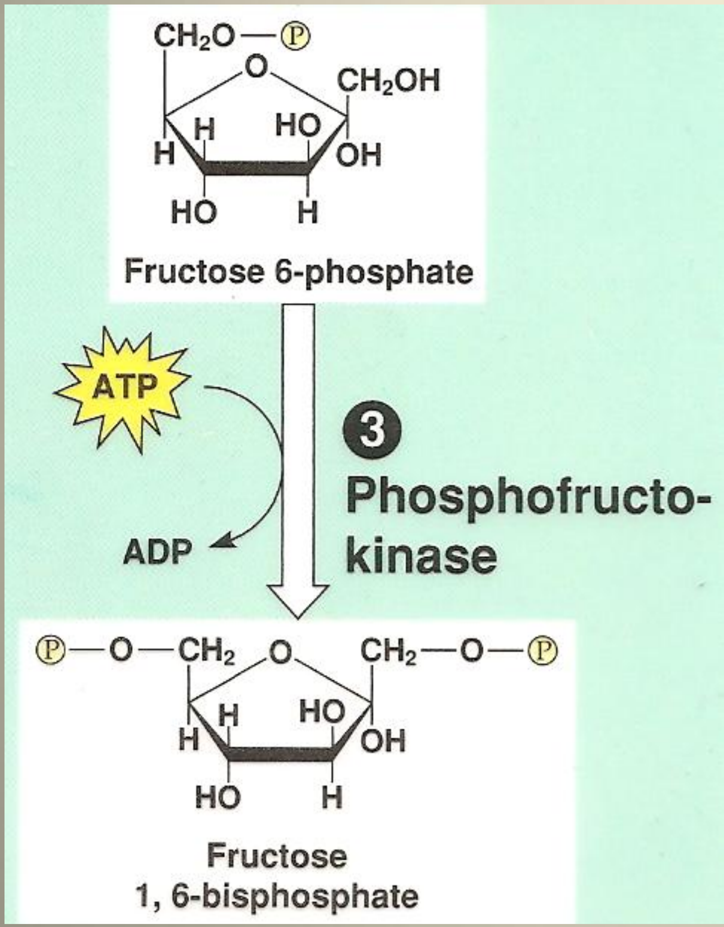


Step 2:

- atoms of molecule are rearranged

- reaction type: isomerization
- enzyme: isomerase
- energy: equilibrium

Glycolysis: Step by Step

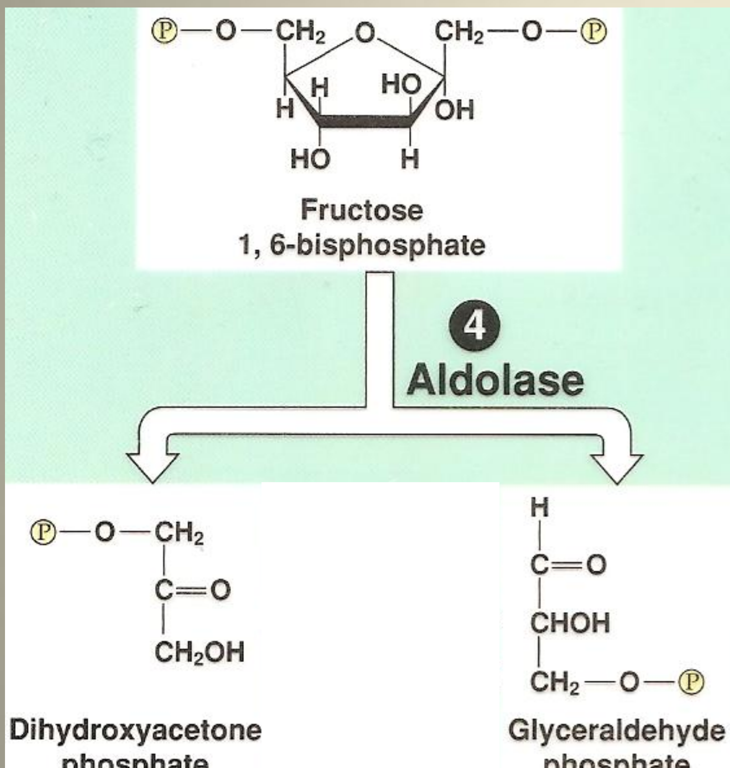


Step 3:

- carbon 1 phosphorylated to cause the molecule to be energetically unstable

- reaction type: phosphorylation
- enzyme: kinase
- energy: absorbed

Glycolysis: Step by Step



Step 4:

- the unstable molecule is split into two molecules

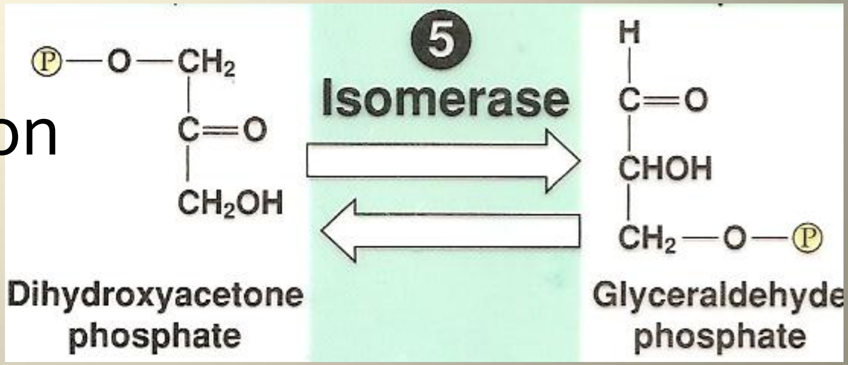
- reaction type: cleavage
- enzyme: lyase
- energy: equilibrium

Glycolysis: Step by Step

Step 5:

- Dihydroxyacetone (DHAP) and glyceraldehyde-3-phosphate (G3P) are isomers
- Only G3P continues in glycolysis
- G3P is used in many other metabolic pathways

- reaction type: isomerization
- enzyme: isomerase
- energy: equilibrium



Energy Payoff Phase

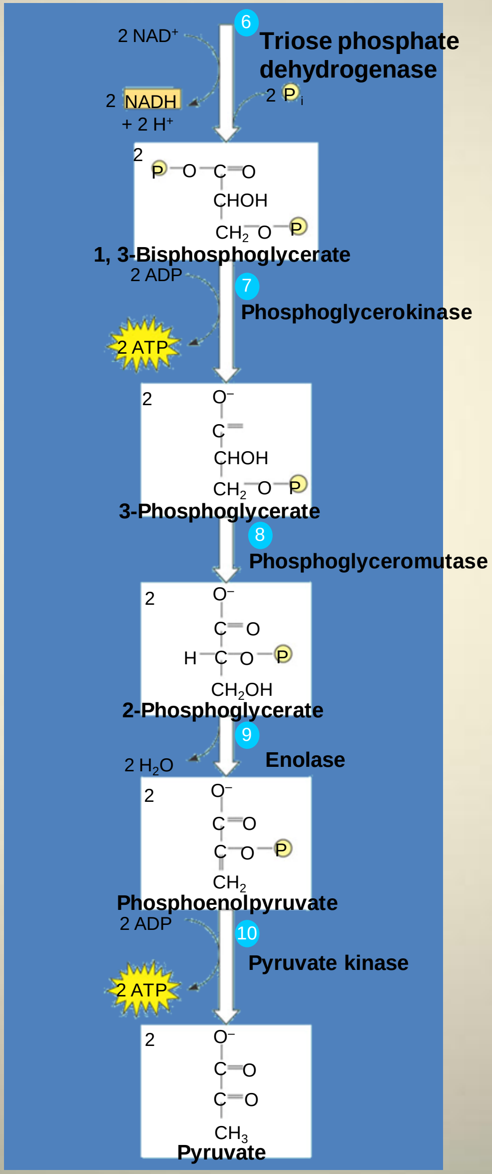
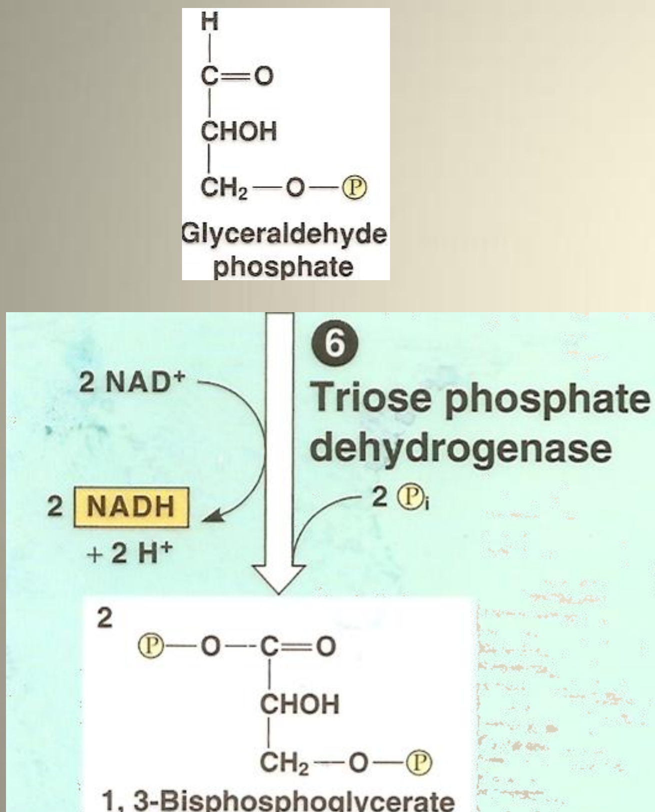


Figure 9.8 B

Glycolysis: Step by Step

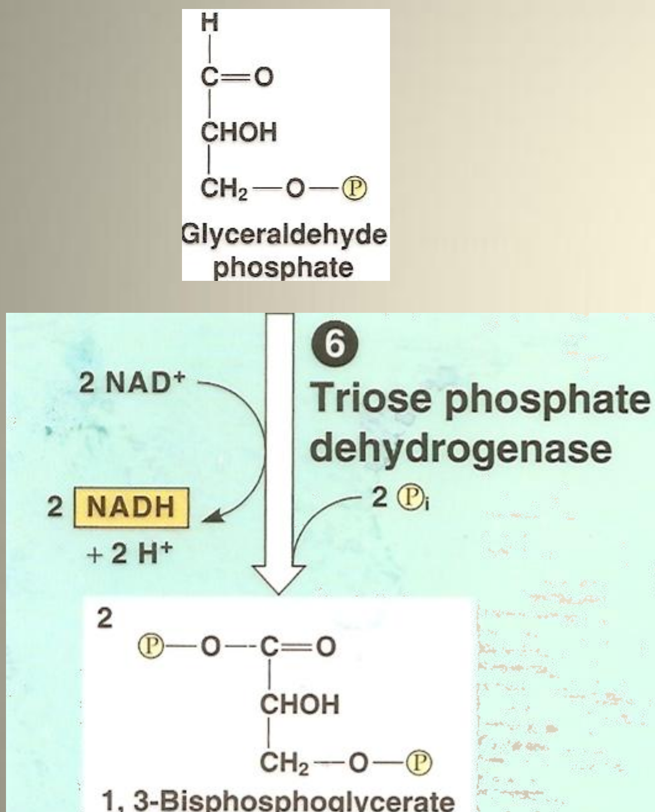


Step 6:

- NADH (energy molecule) is created

- reaction type: redox and phosphorylation
- enzyme: dehydrogenase
- energy: released

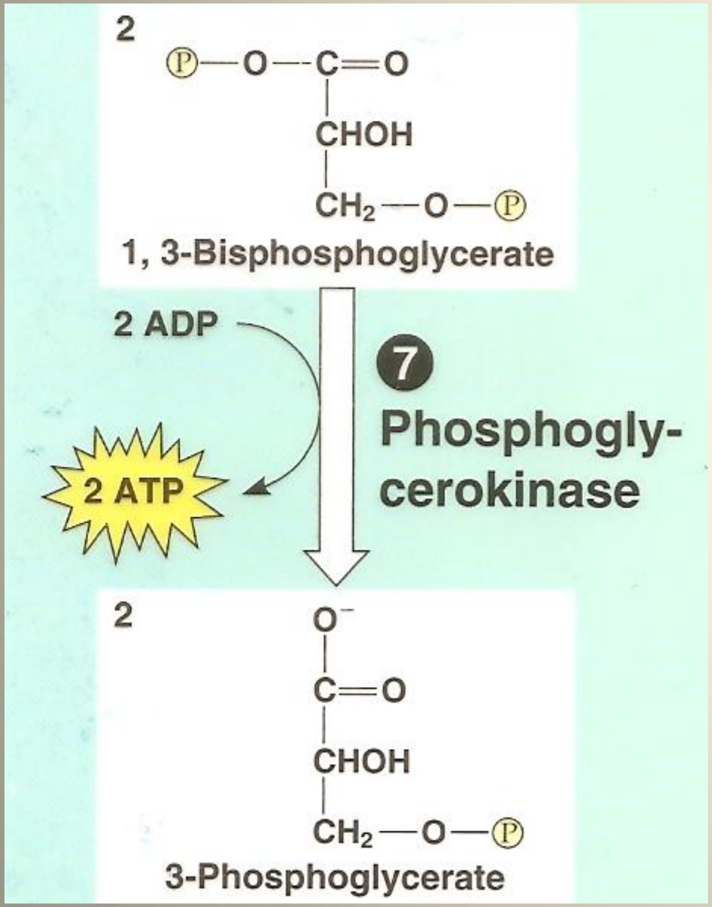
Glycolysis: Step by Step



Dehydrogenase functions:

- Transfers electrons from G3P to the oxidizing agent NAD+ to form NADH
- Uses energy from exergonic transfer of electrons to add a phosphate from the cytosol to the oxidized G3P to form 1, 3-Bisphosphoglycerate

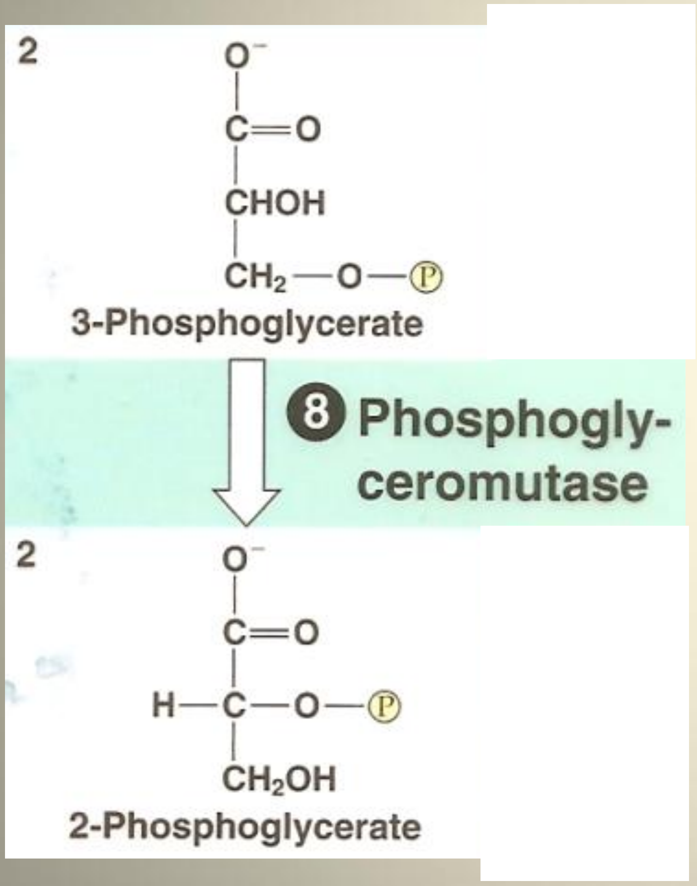
Glycolysis: Step by Step



Step 7:

- ADP phosphorylation to create ATP
- reaction type: substrate-level phosphorylation
- enzyme: kinase
- energy: released

Glycolysis: Step by Step

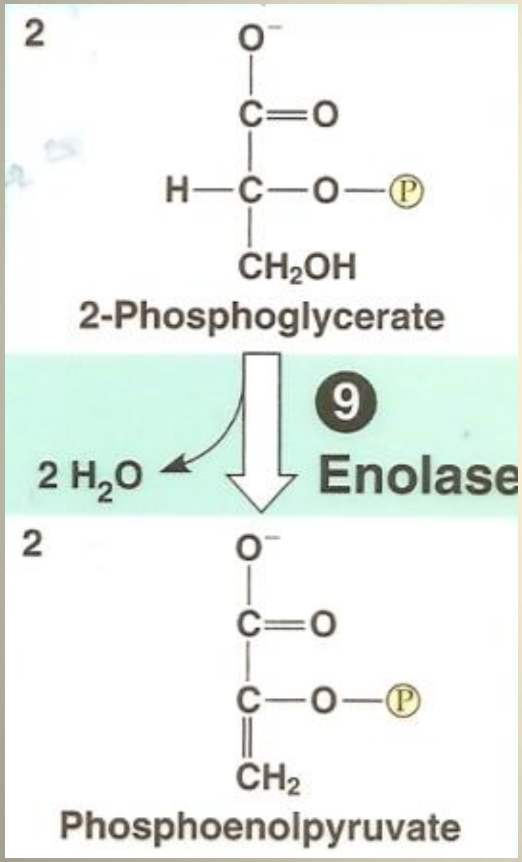


Step 8:

- phosphate moved from carbon 3 to carbon 2

- reaction type: isomerization
- enzyme: isomerase
- energy: equilibrium

Glycolysis: Step by Step

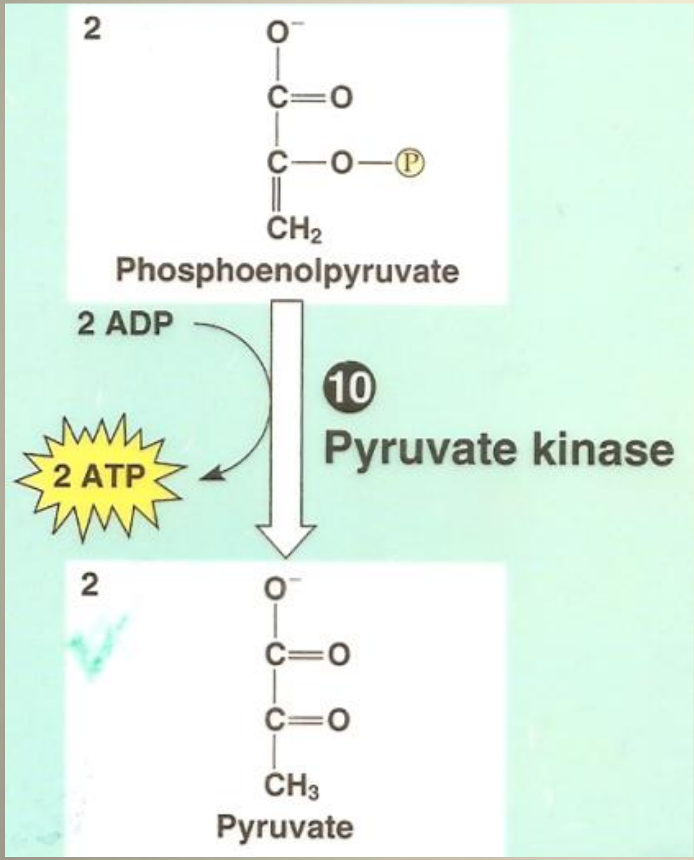


Step 9:

- water removed to set up next reaction

- reaction type: dehydration
- enzyme: lyase
- energy: released

Glycolysis: Step by Step



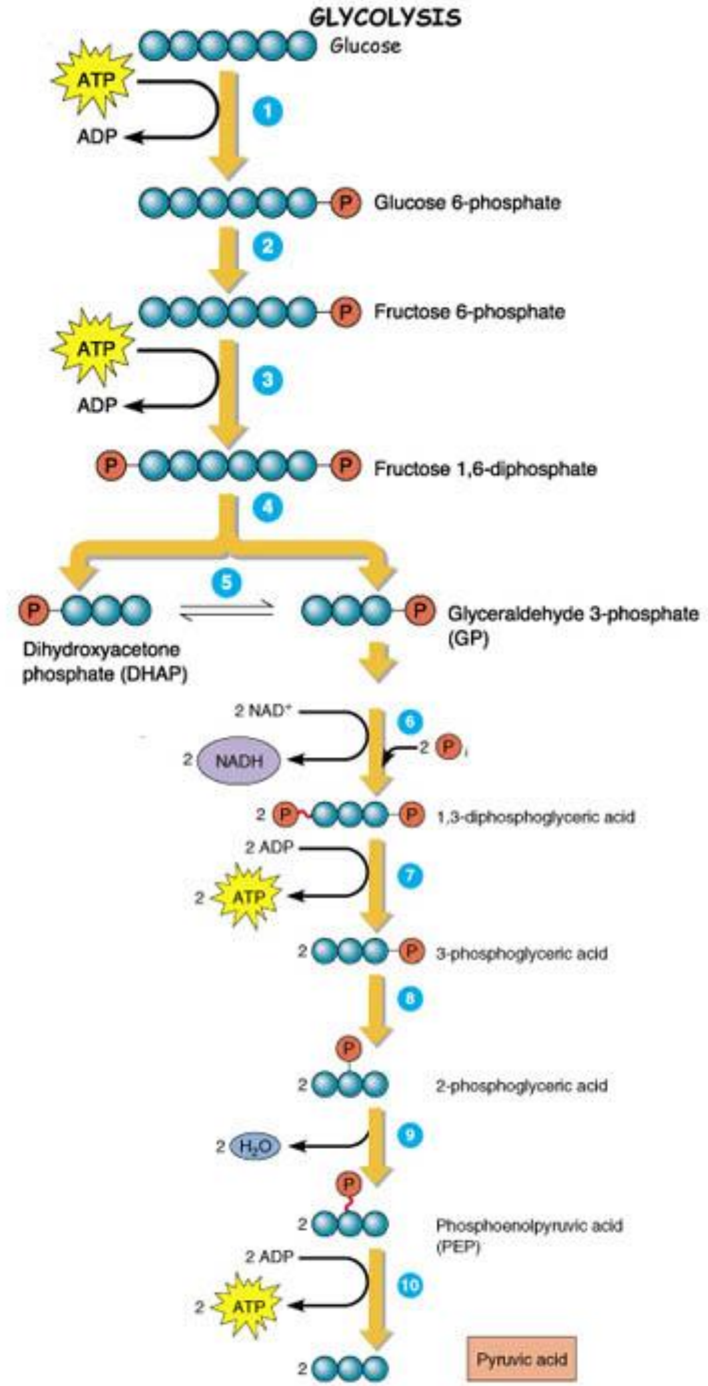
Step 10:

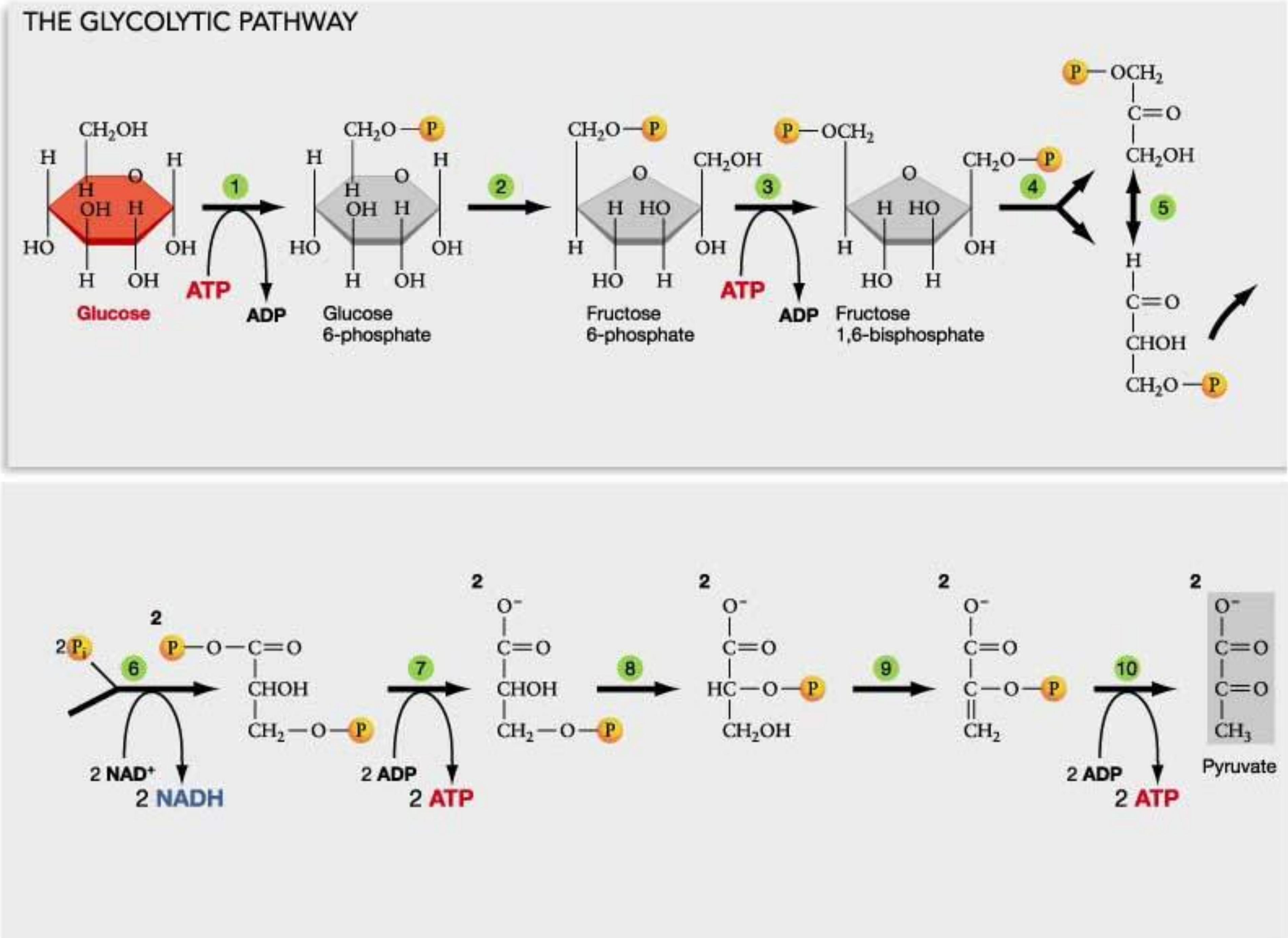
- ADP phosphorylation to ATP

- reaction type: substrate-level phosphorylation
- enzyme: kinase
- energy: released

Glycolysis Summary

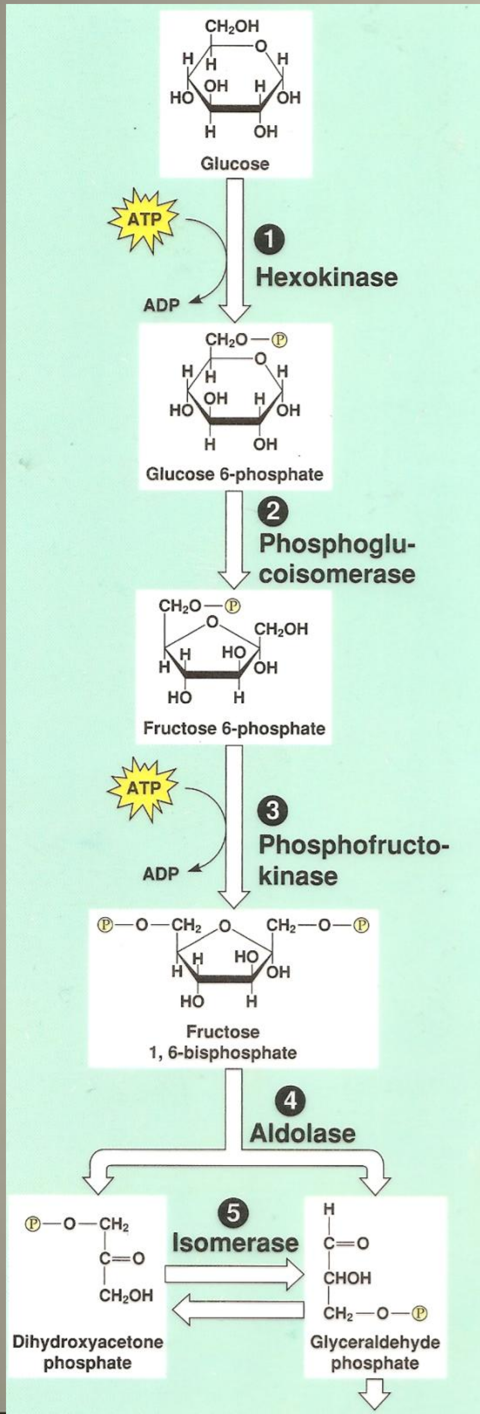
- glucose → 2 pyruvate
- net 2 ATP molecules produced
  - 2 used; 4 generated
- 2 NADH molecules produced
- Animation: http://highered.mcgraw-hill.com/sites/0072507470/student_view0/chapter25/animation__how_glycolysis_works.html



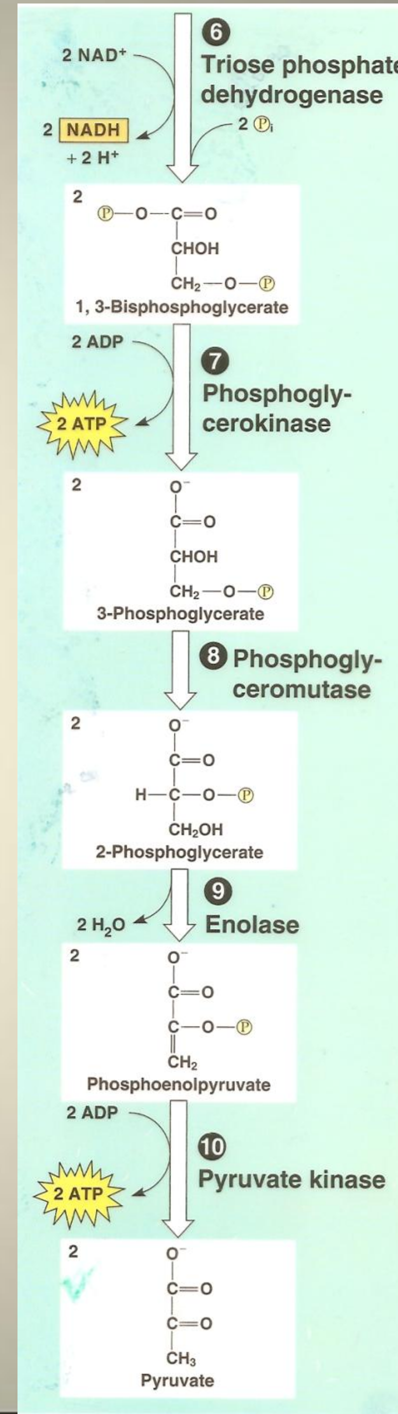


http://www.uic.edu/classes/bios/bios100/lecturesf04am/lect12.htm

Glycolysis



Glucose
ATP
ADP
1 Hexokinase
Glucose 6-phosphate
2 Phosphoglu-coisomerase
Fructose 6-phosphate
ATP
ADP
3 Phosphofructo-kinase
Fructose 1, 6-bisphosphate
4 Aldolase
5 Isomerase
Dihydroxyacetone phosphate
Glyceraldehyde phosphate



6 Triose phosphate dehydrogenase
2 NAD+
2 NADH
+ 2 H+
2 Pi
1, 3-Bisphosphoglycerate
2 ADP
2 ATP
7 Phosphogly-cerokinase
3-Phosphoglycerate
8 Phosphogly-ceromutase
2-Phosphoglycerate
9 Enolase
2 H2O
Phosphoenolpyruvate
2 ADP
2 ATP
10 Pyruvate kinase
Pyruvate

Molecule Count: Aerobic

	ATP	NADH	$FADH_2$	CO_2
Glycolysis				
Pyruvate Oxidation				
Krebs				
Subtotal				
Conversion in ETC				

Molecule Count: Aerobic

	ATP	NADH	$FADH_2$	CO_2
Glycolysis	2	2	0	0
Pyruvate Oxidation				
Krebs				
Subtotal				
Conversion in ETC				

Pyruvate Juncture in Metabolism

- Pyruvate will continue to the Kreb cycle and the ETC to synthesize ATP only in the presence of O2

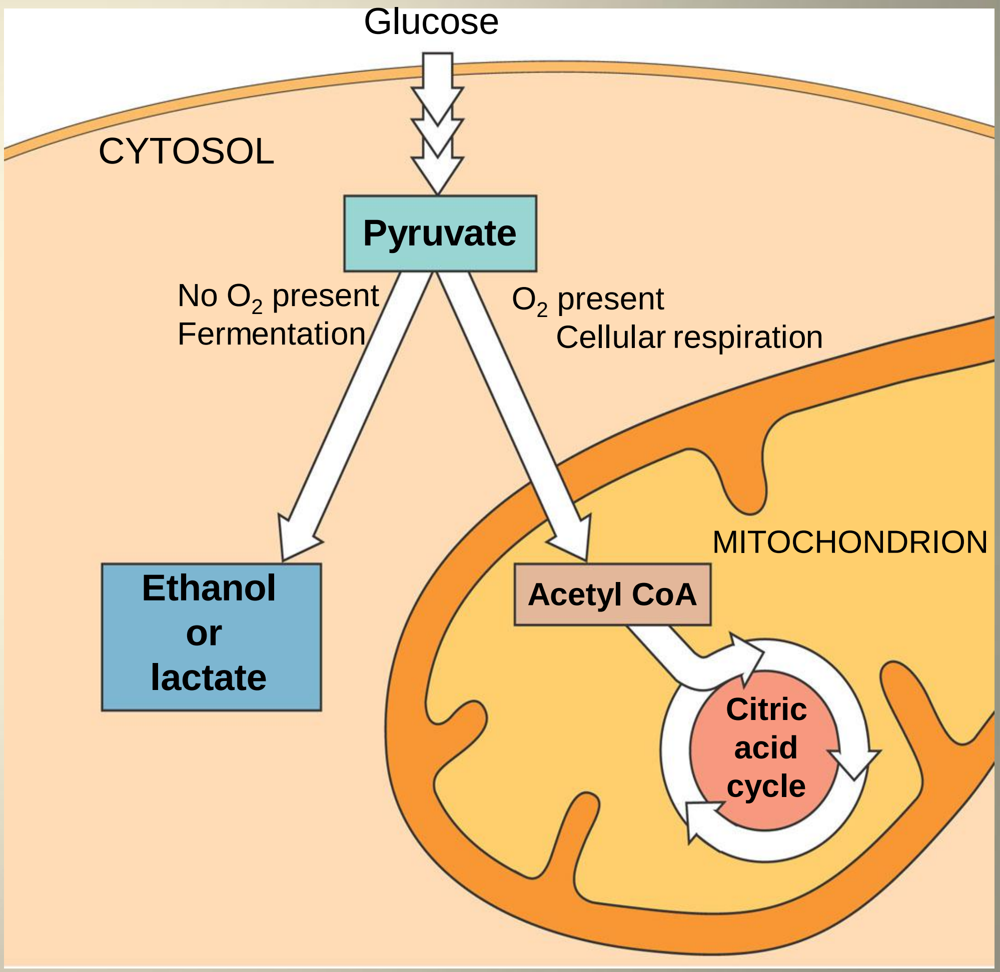


Figure 9.18

Anaerobic Respiration

- Anaerobic conditions: without oxygen
- Cells can only utilize glycolysis to make ATP
- Cells without mitochondria can only utilize glycolysis
- Glycolysis couples with fermentation to produce ATP

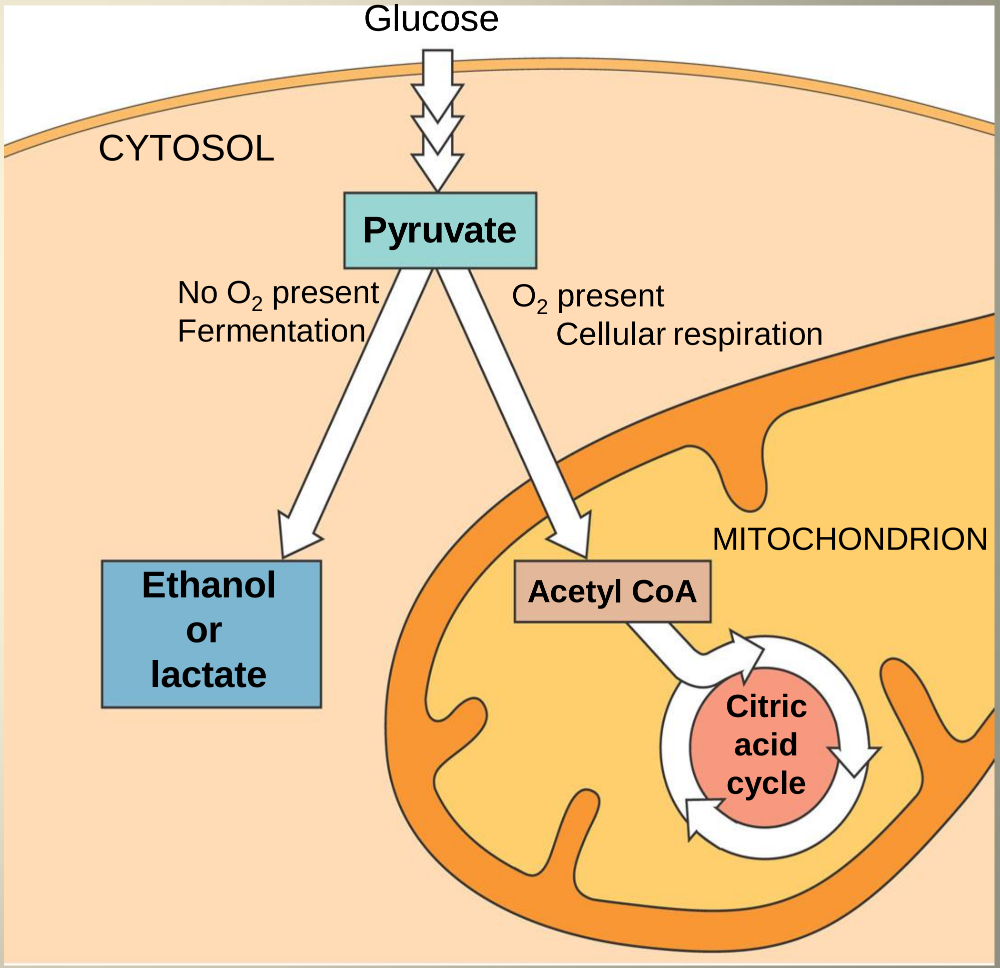


Figure 9.18

Types of Fermentation

- Fermentation consists of
  - Glycolysis plus reactions that regenerate NAD+, which can be reused by glycolysis
- In alcohol fermentation
  - Pyruvate is converted to ethanol in two steps, one of which releases CO_2
- During lactic acid fermentation
  - Pyruvate is reduced directly to NADH to form lactate as a waste product

Anaerobic Respiration

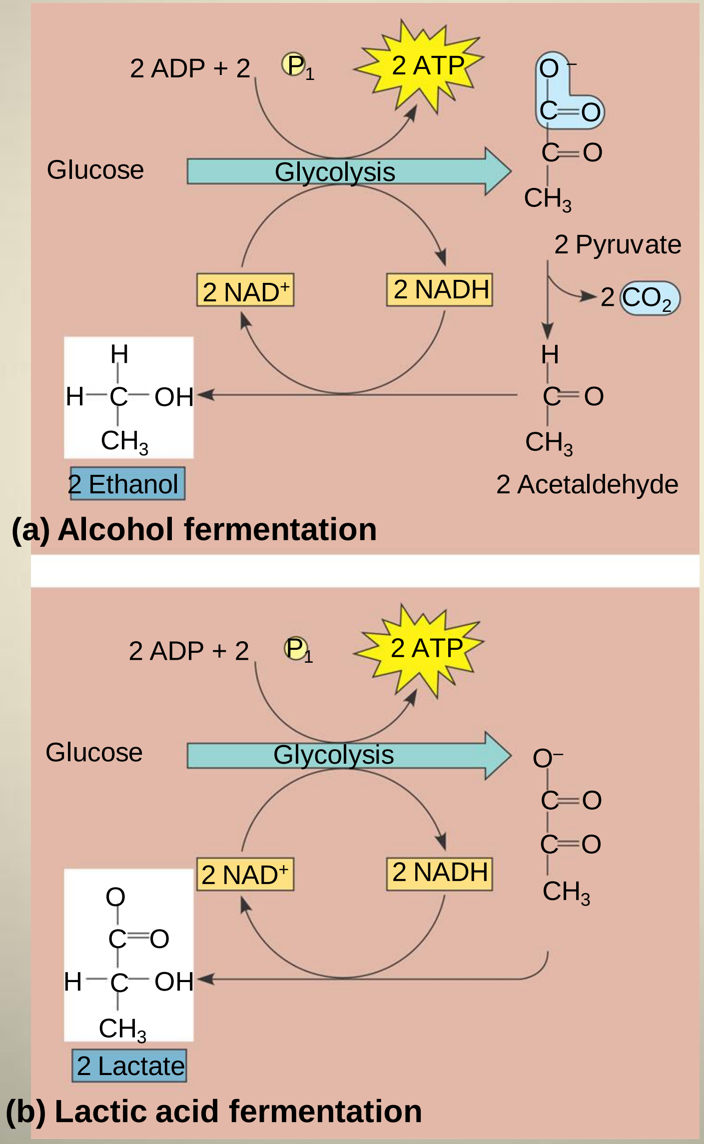
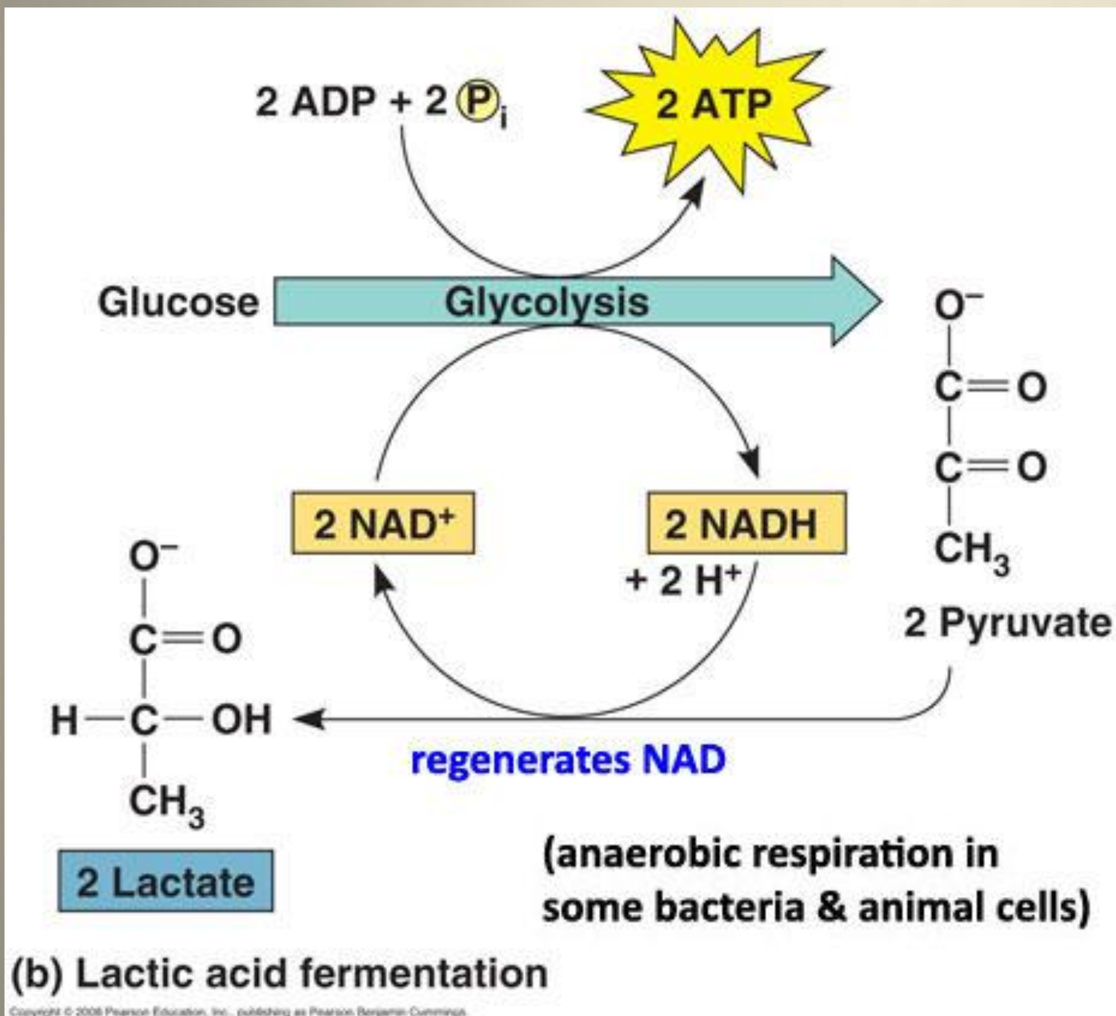


Figure 9.17

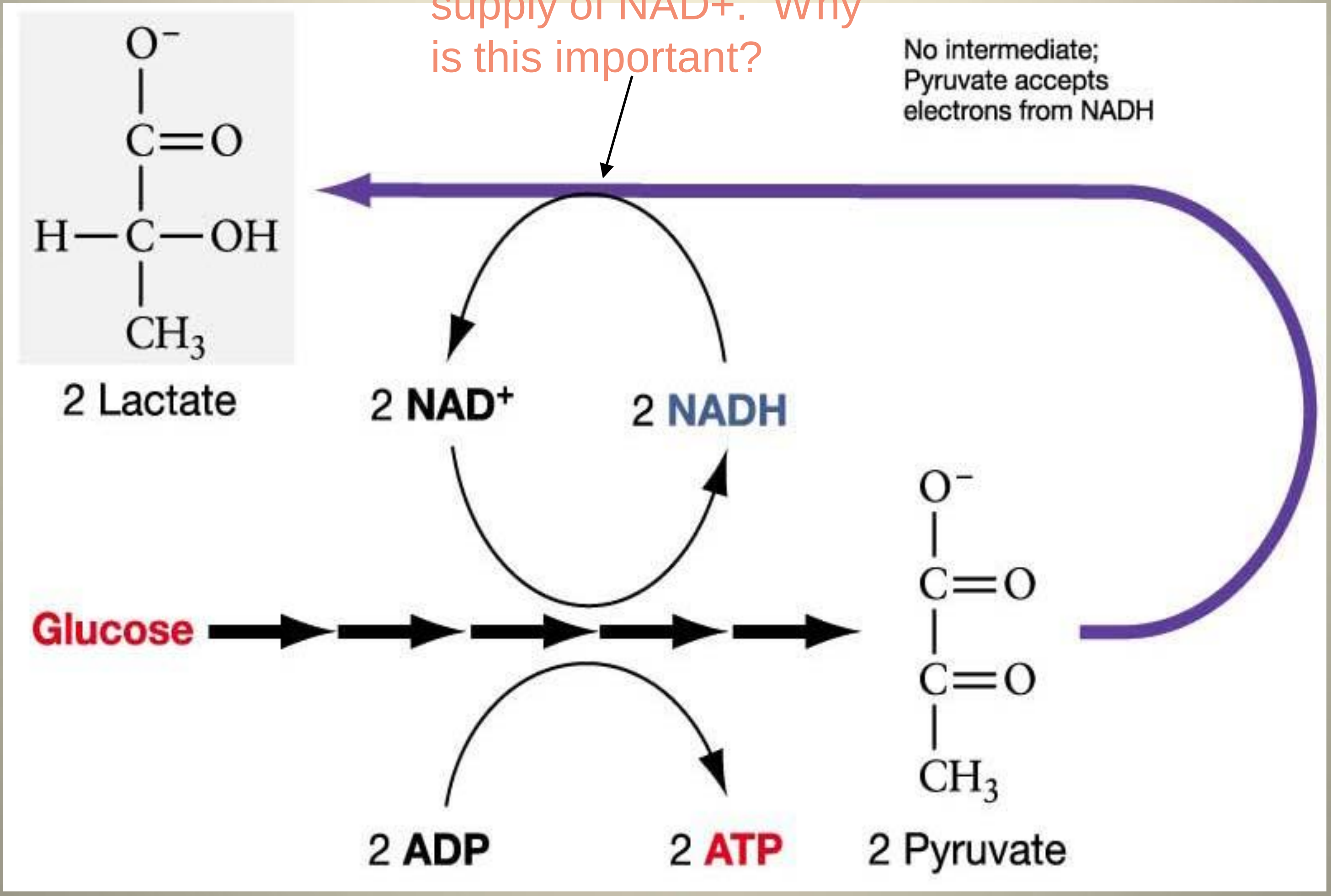
Lactic Acid Fermentation



- Lactate dehydrogenase converts pyruvate into lactic acid
- Final product: lactic acid / lactate (3C)

Lactic Acid Fermentation

Need to replenish supply of NAD+. Why is this important?

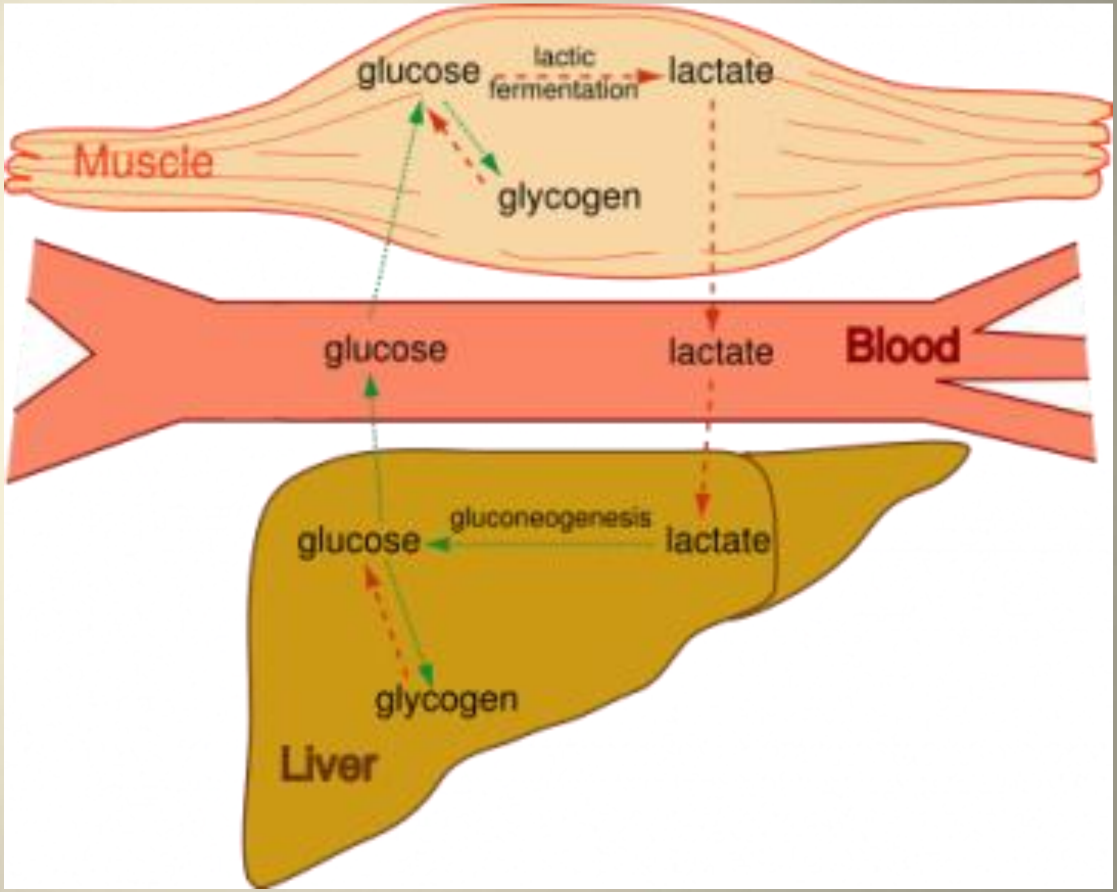


Lactic Acid Fermentation

- Occurs in some fungi and bacteria
  - Useful in the dairy industry: cheese & yogurt
- Occurs in humans during anaerobic conditions
  - What could we be doing to cause our cells to face anaerobic conditions?

Lactic Acid Fermentation

- Lactic acid build up in muscle is what causes muscle ache / pain
- Carried to liver where it can be converted back to pyruvate



Lactic Acid Fermentation

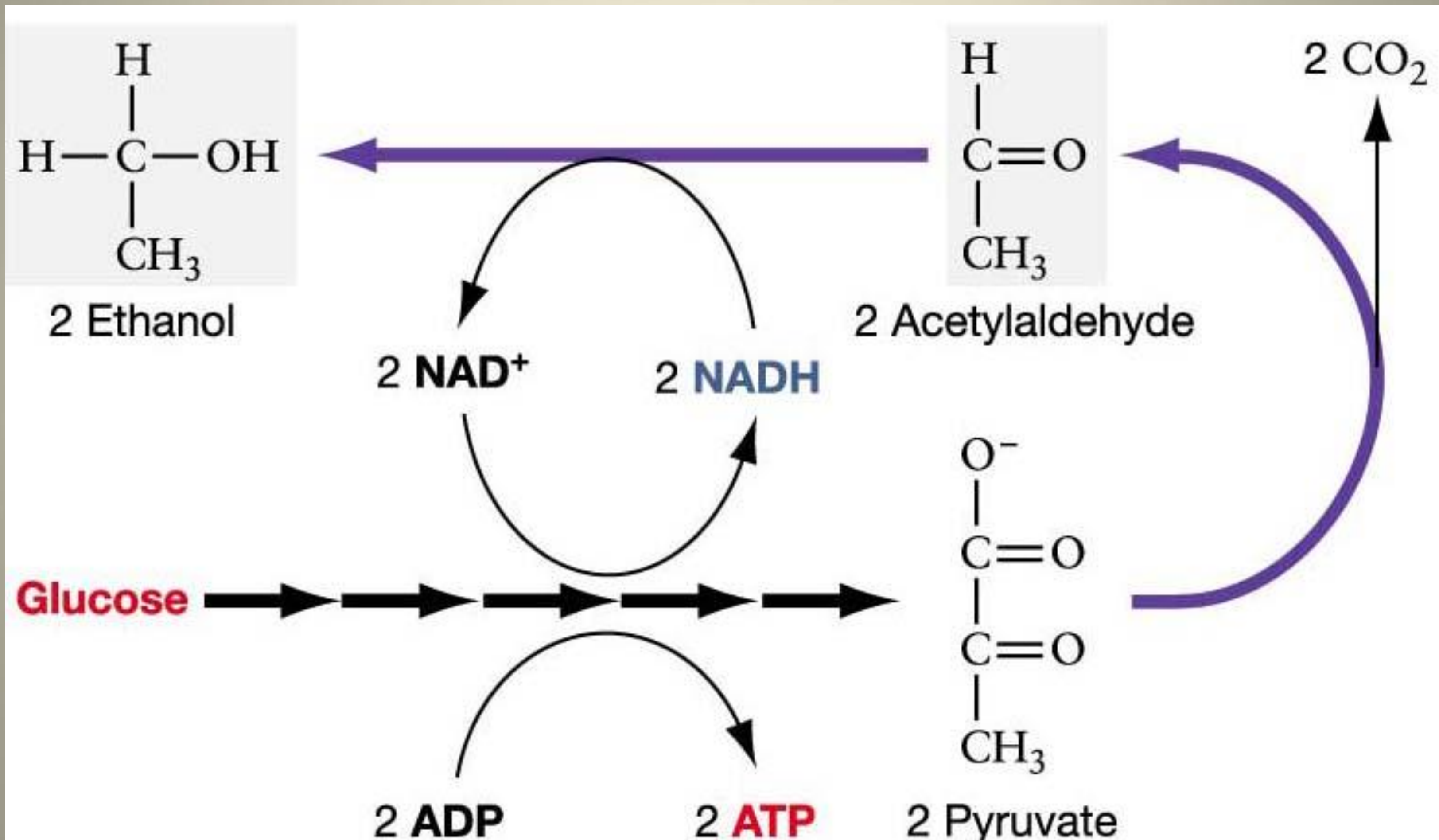
Questions:

- Why does the body feel fatigue when it is undergoing anaerobic respiration?
- Why does rubbing aching muscles often help to reduce the pain faster?

Alcohol Fermentation

- Pyruvate is decarboxylated (loss of CO_2) into acetaldehyde (a 2 carbon compound)
- Alcohol dehydrogenase converts acetaldehyde into ethanol (2C)
- NADH is converted back into NAD^+ for glycolysis to continue to occur
- Ethanol will not be converted back to pyruvate even if O_2 concentration has increased

Alcohol Fermentation



Alcohol Fermentation

- Occurs in yeast (and other organisms without mitochondria)
- Products of alcohol fermentation useful in industry:
  - Ethanol: brewing and wine making
  - CO_2: bread production

Purpose of Fermentation

- If no new ATP is made during the process of fermentation, then why doesn't the metabolic process just end at pyruvate when in anaerobic conditions?
- What is the main purpose of fermentation?

Fermentation Summary

- lactic acid fermentation
  - 2 pyruvate → 2 lactic acid
  - NADH → NAD+
- alcohol fermentation
  - 2 pyruvate → 2 acetylaldehyde → 2 ethanol
  - 2 CO_2 released
  - NADH → NAD+

Molecule Count: Anaerobic

	ATP	NADH	$FADH_2$
Glycolysis	2	2	0
Fermentation			
Subtotal			

Molecule Count: Anaerobic

	ATP	NADH	$FADH_2$
Glycolysis	2	2	0
Fermentation	0	-2	0
Subtotal	2	0	0

Glycolysis Links

- Tutorial: http://www.youtube.com/watch?v=DJrA64rBhSk
- Glucose song: http://www.youtube.com/watch?v=6JGXayUyNVw
- Glycolysis rap: http://www.youtube.com/watch?v=YyNowx2AHfE&feature=related