Anaerobic Fermentation

BTEC 101

Bacterial Metabolism

- Metabolism
  - represents the sum of chemical changes that converts nutrients, the “raw materials” necessary to nourish living organisms, into energy and the chemically complex finished products of cells

Biological Metabolism allows step-wise tapping of stored Energy

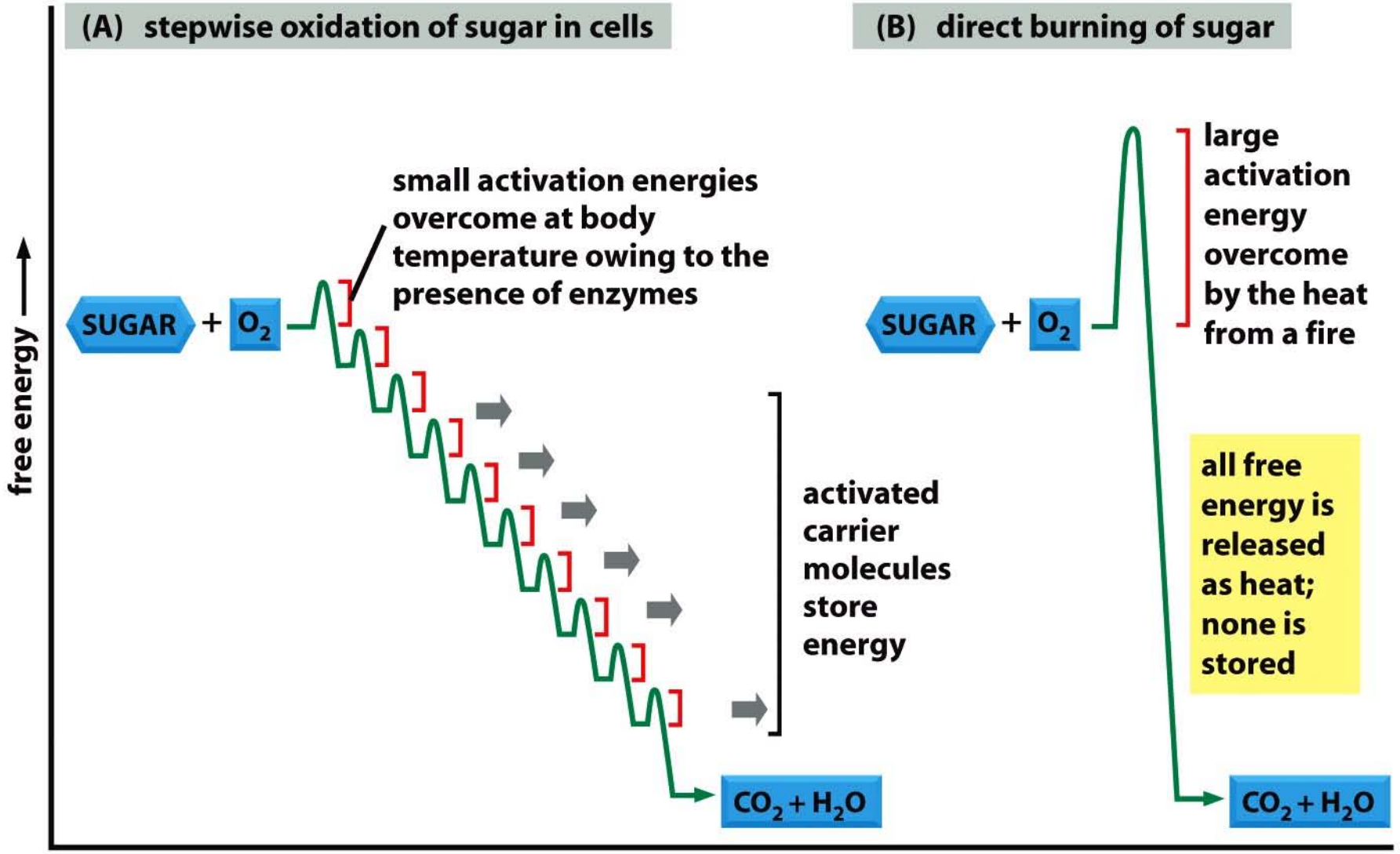


Figure 2-69 Molecular Biology of the Cell 5/e (© Garland Science 2008)

Bacterial Metabolism

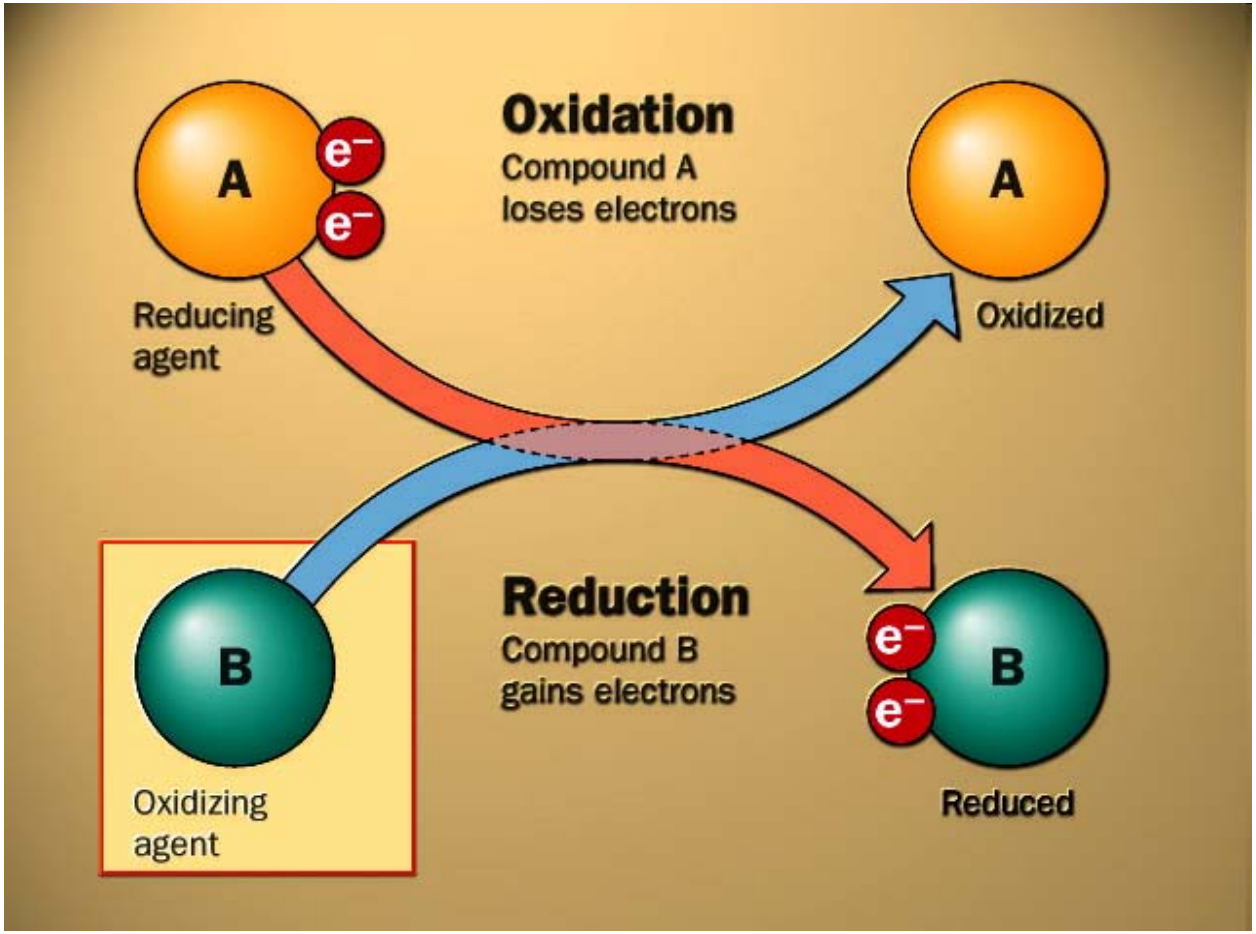
- To make energy, a cell uses the following pathways:
  - Glycolysis
  - Krebs Cycle (Citric Acid Cycle or Tricarboxylic acid cycle TCA)
  - Electron Transport Chain (oxidative phosphorylation)

Basic Concepts: Oxidation

- **Oxidation**: A reaction that involves the overall loss of electrons from a specific molecule or atom
  - Removal of electrons or hydrogens
  - Addition of an oxygen

Basic Concept: Reduction

- **Reduction**: A reaction that involves the overall gain of electrons from a specific molecule or atom
  - Addition of electrons or hydrogens
  - Removal of an oxygen


Oxidation
Compound A
loses electrons
A
e⁻
e⁻
Reducing
agent
A
Oxidized
Reduction
Compound B
gains electrons
B
Oxidizing
agent
e⁻
e⁻
B
Reduced

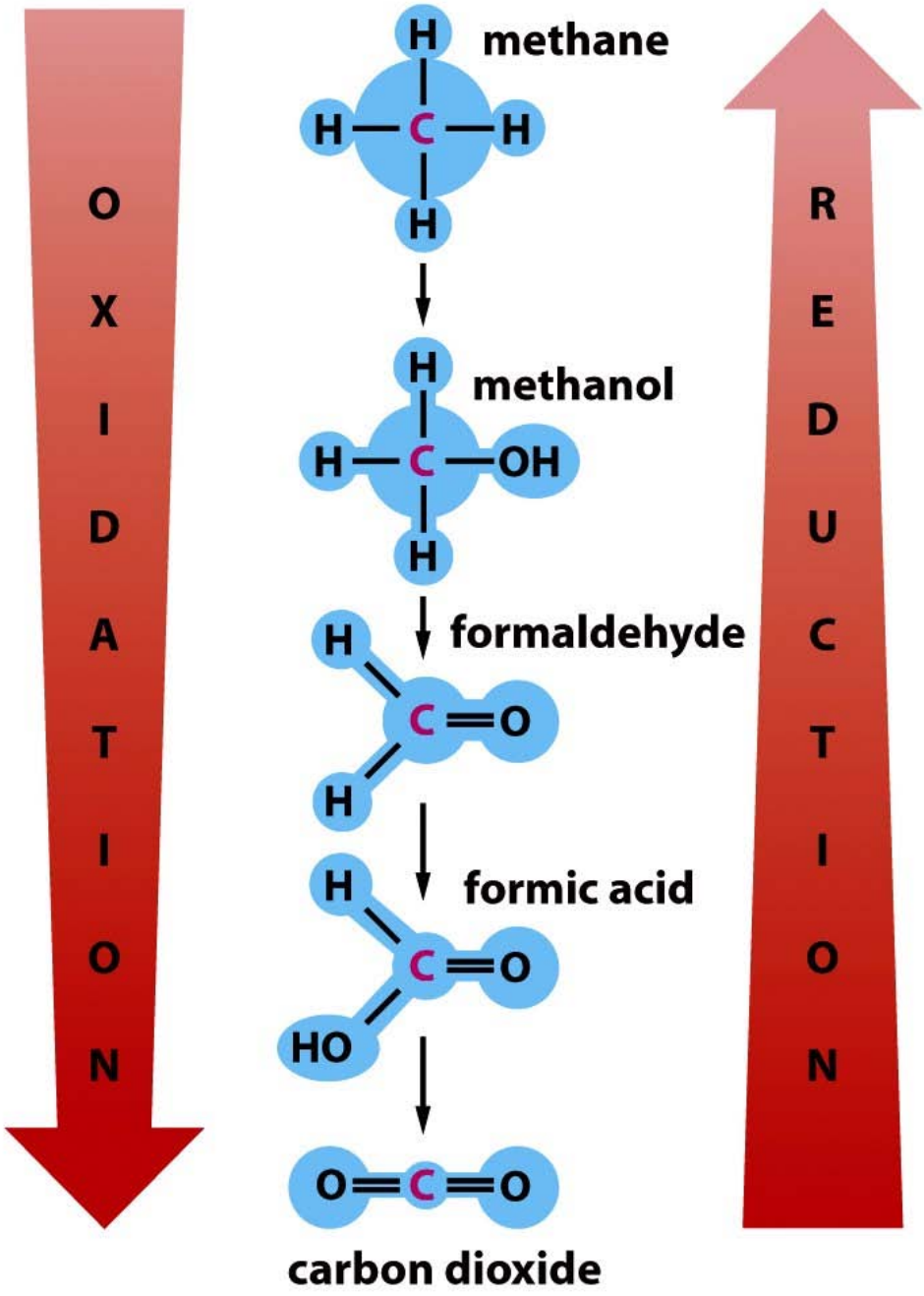


Figure 2-43b Molecular Biology of the Cell 5/e (© Garland Science 2008)

Activated Carrier Molecules
(energy currency)

- ATP = Most abundant energy carrier in cells
- NADH = Important electron carrier
- Acetyl CoA
- S-adenosylmethionine
- Carboxylated biotin

Energy Rich Molecule example: ATP

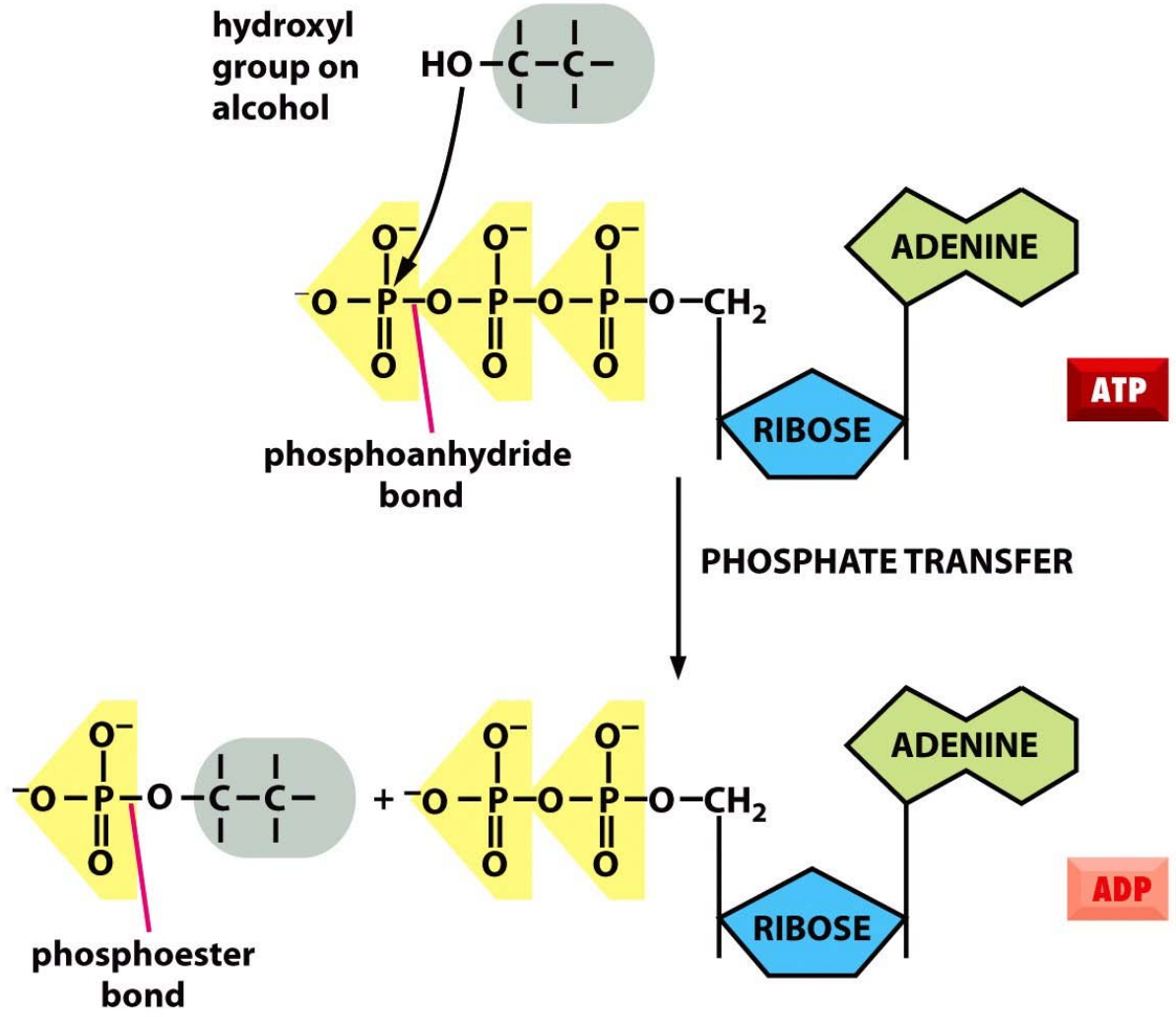


Figure 2-58 Molecular Biology of the Cell 5/e (© Garland Science 2008)

ATP supplies energy to drive a reaction

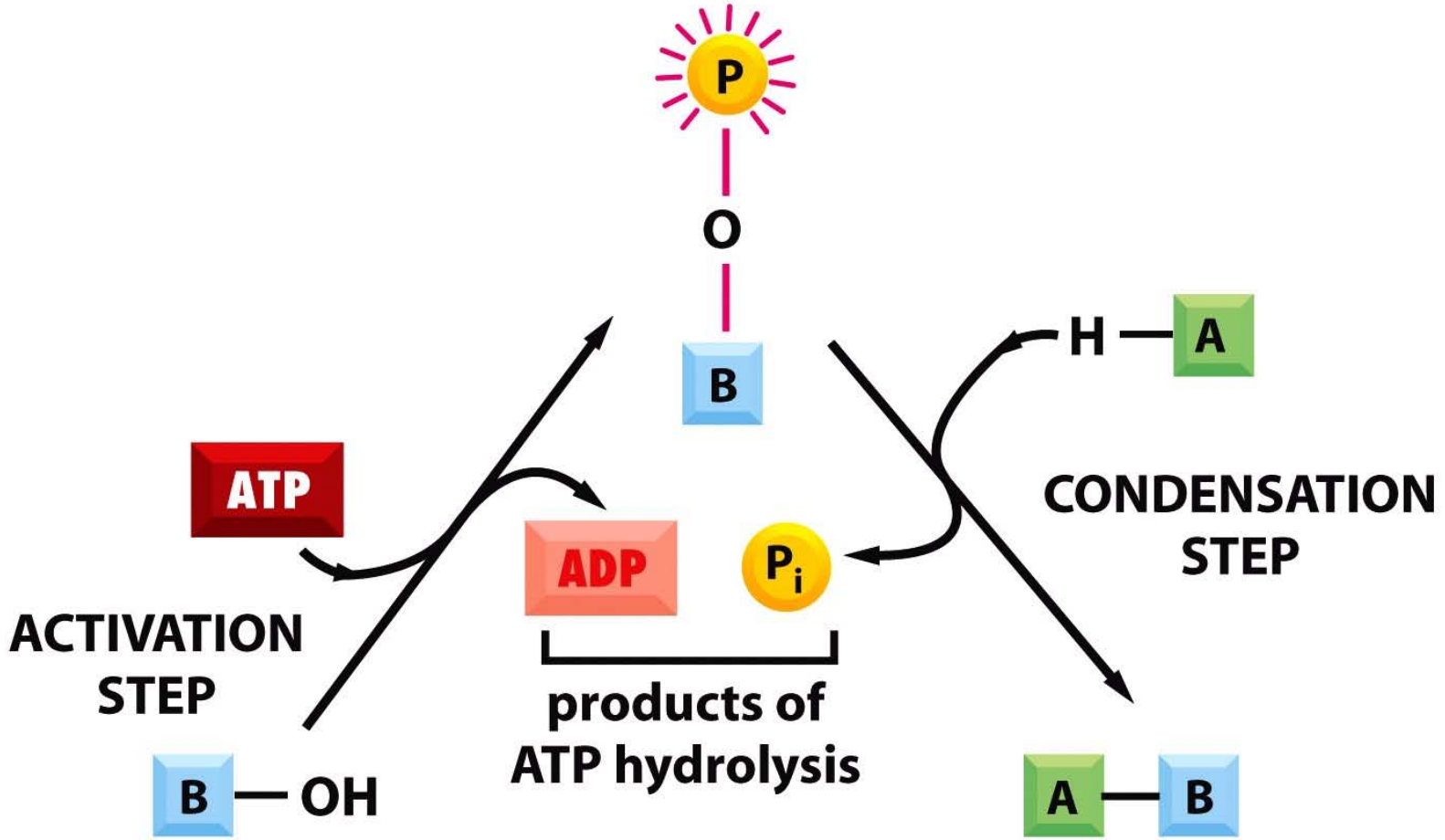


Figure 2-59a Molecular Biology of the Cell 5/e (© Garland Science 2008)

Oxidation –reduction represents trapping of energy

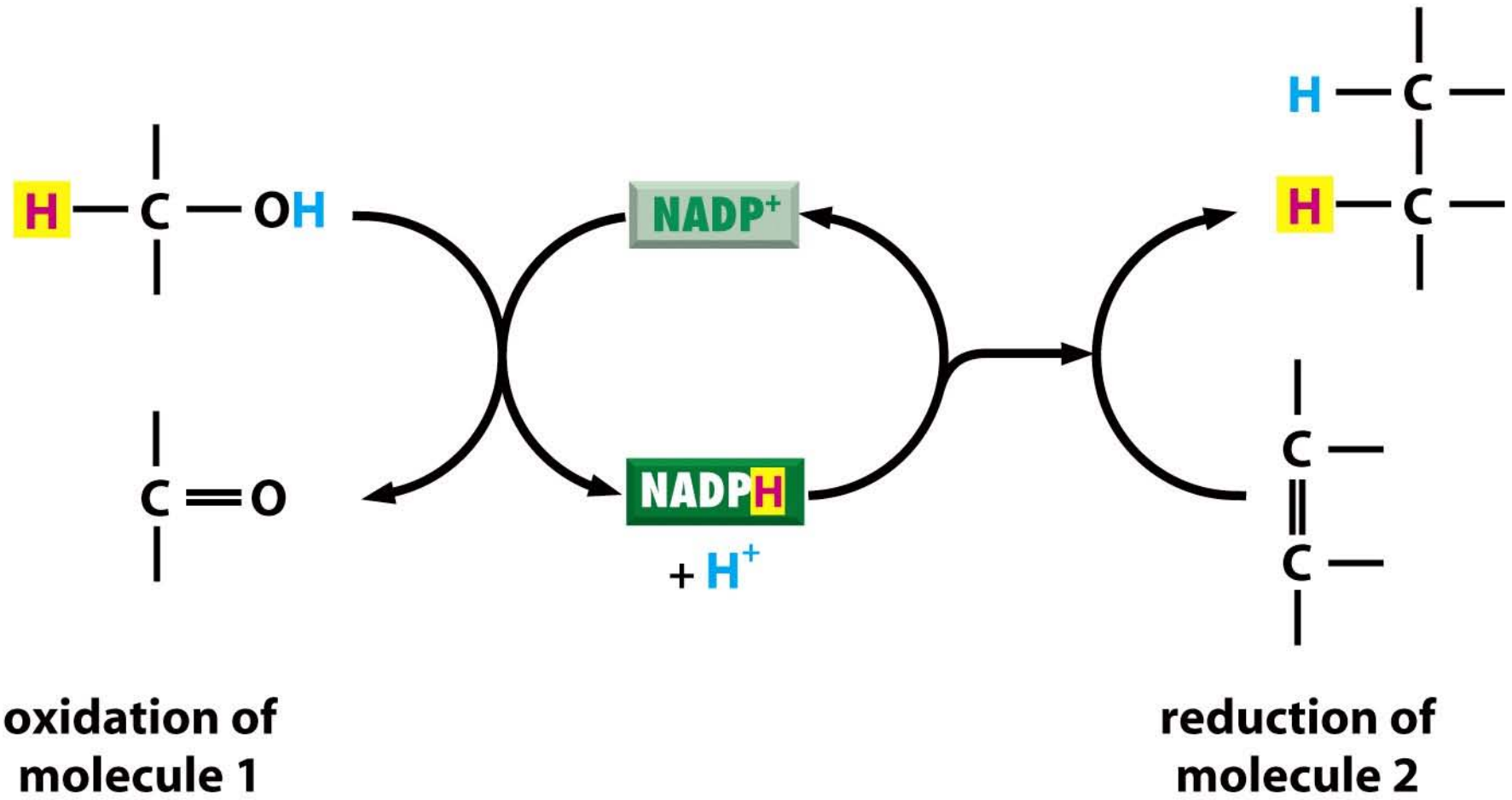


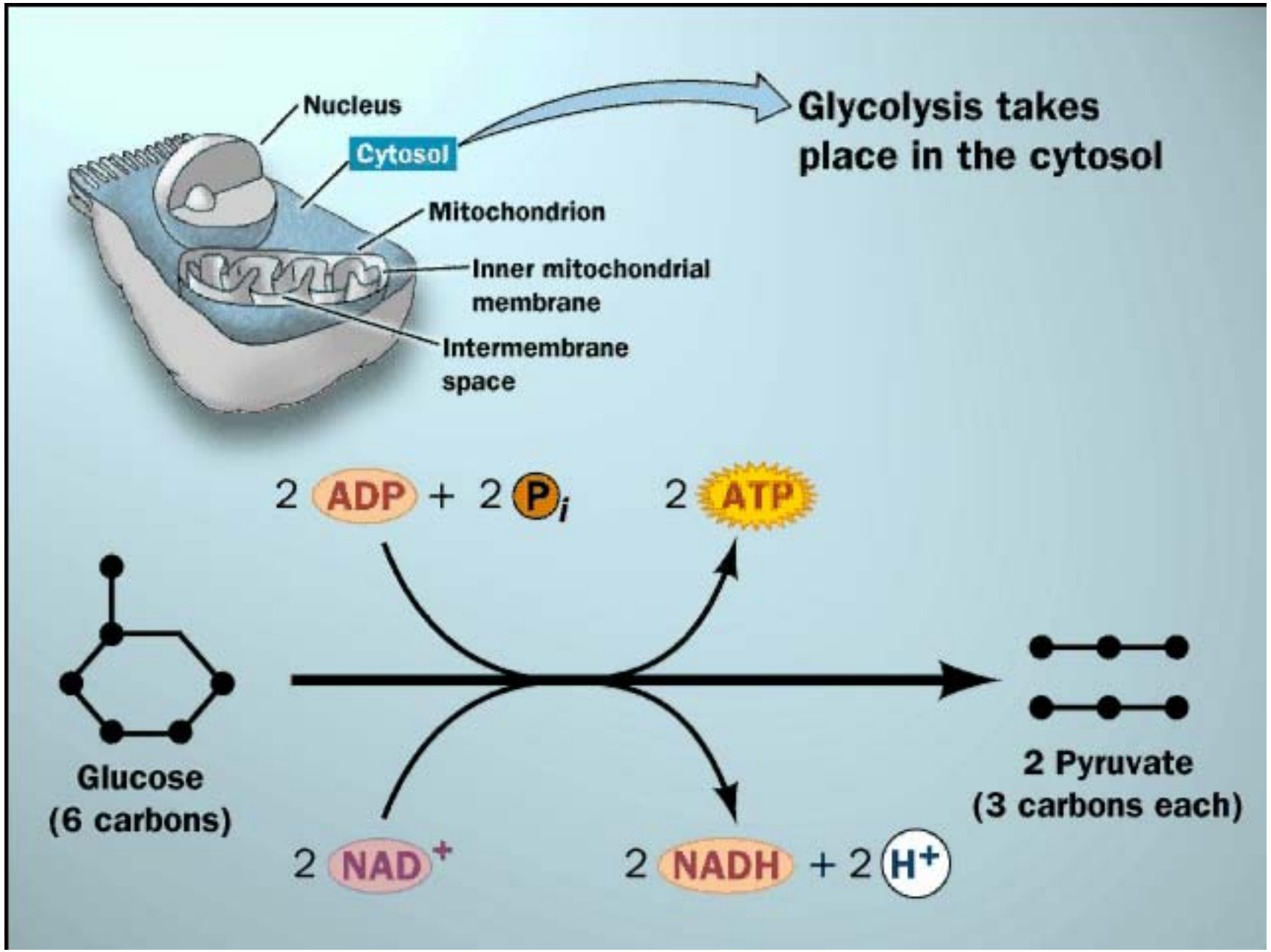
Figure 2-60a Molecular Biology of the Cell 5/e (© Garland Science 2008)

Glycolysis: The Universal Energy Pathway

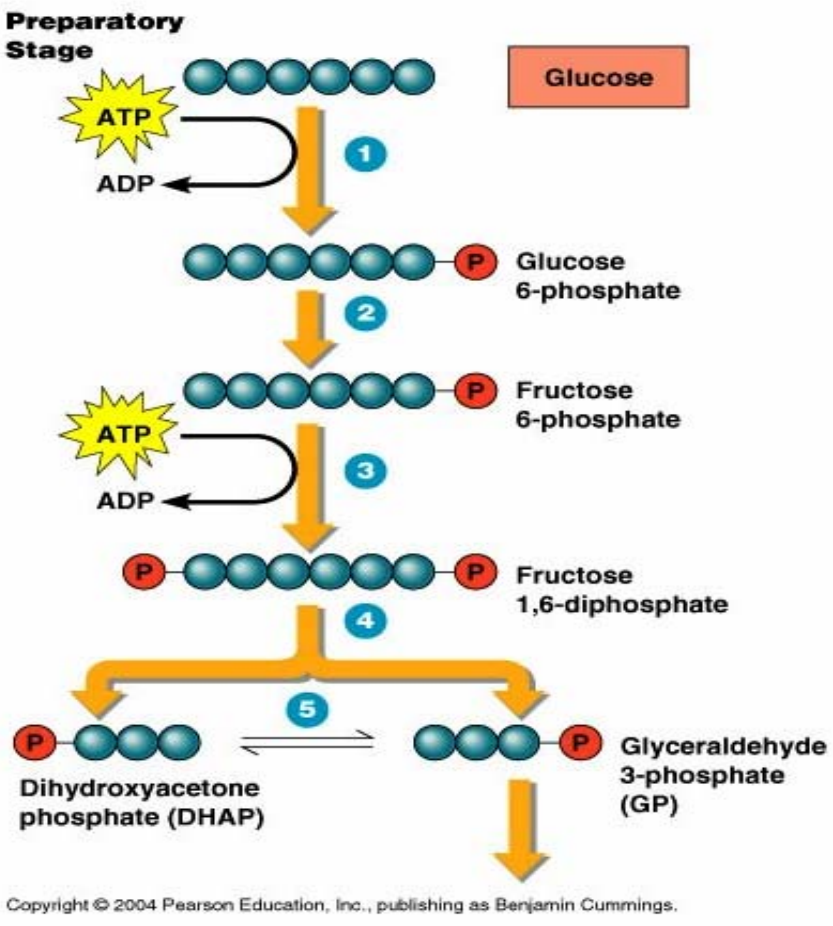
- Is carried out by all living cells
- Produces energy without the involvement of oxygen
- Is a source of short term energy when oxygen is limited
- Works by extracting energy from nutrient molecules
- **Provides precursors for aerobic respiration** (Krebs Cycle and electron transport), anaerobic fermentation (lactic acid or alcoholic fermentations), and anaerobic respiration

Glycolysis

- Glycolysis is a central ATP producing pathway
- Converts Glucose → 2 pyruvates
  - Uses 2 ATP
  - Generates 4 ATP
  - Generates 2 NADH

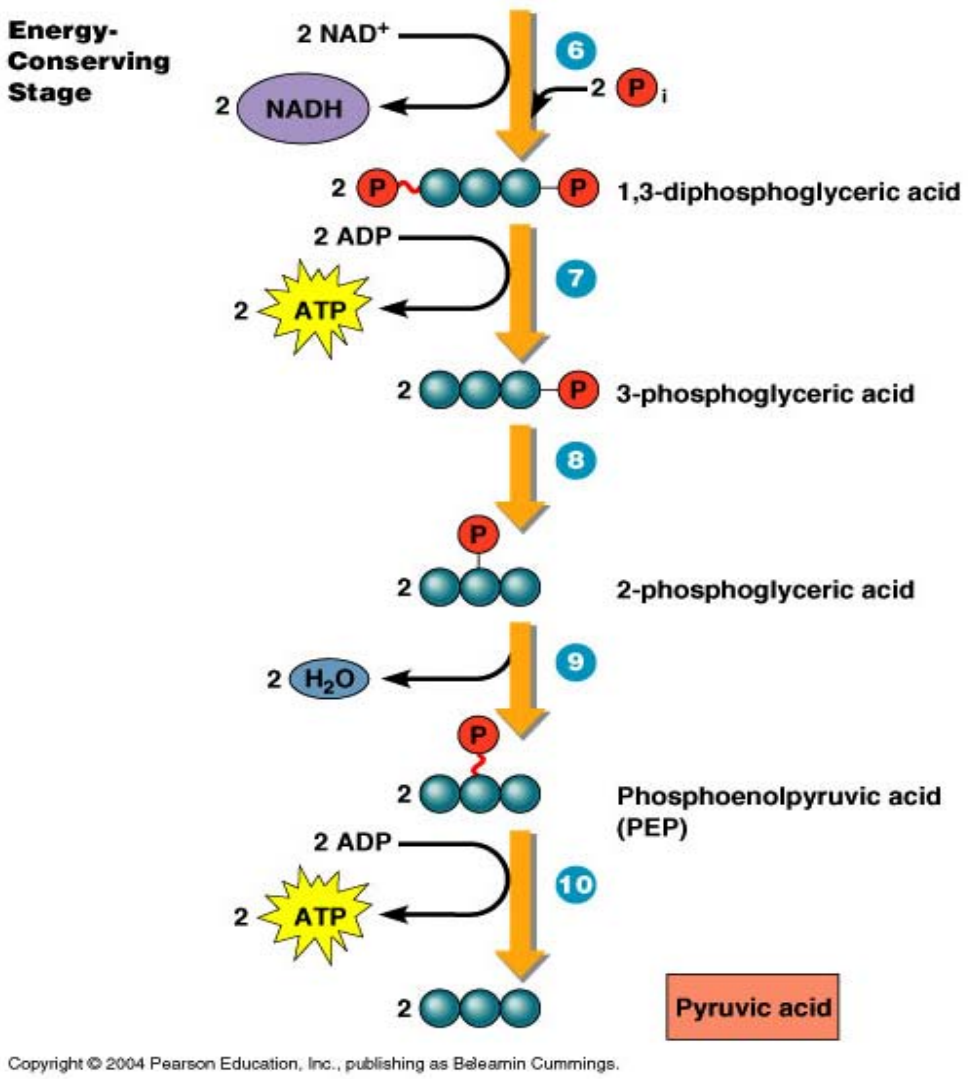

Nucleus
Cytosol
Glycolysis takes place in the cytosol
Mitochondrion
Inner mitochondrial membrane
Intermembrane space
2 ADP + 2 Pi
2 ATP
Glucose (6 carbons)
2 Pyruvate (3 carbons each)
2 NAD+
2 NADH + 2 H+

Initial reactions



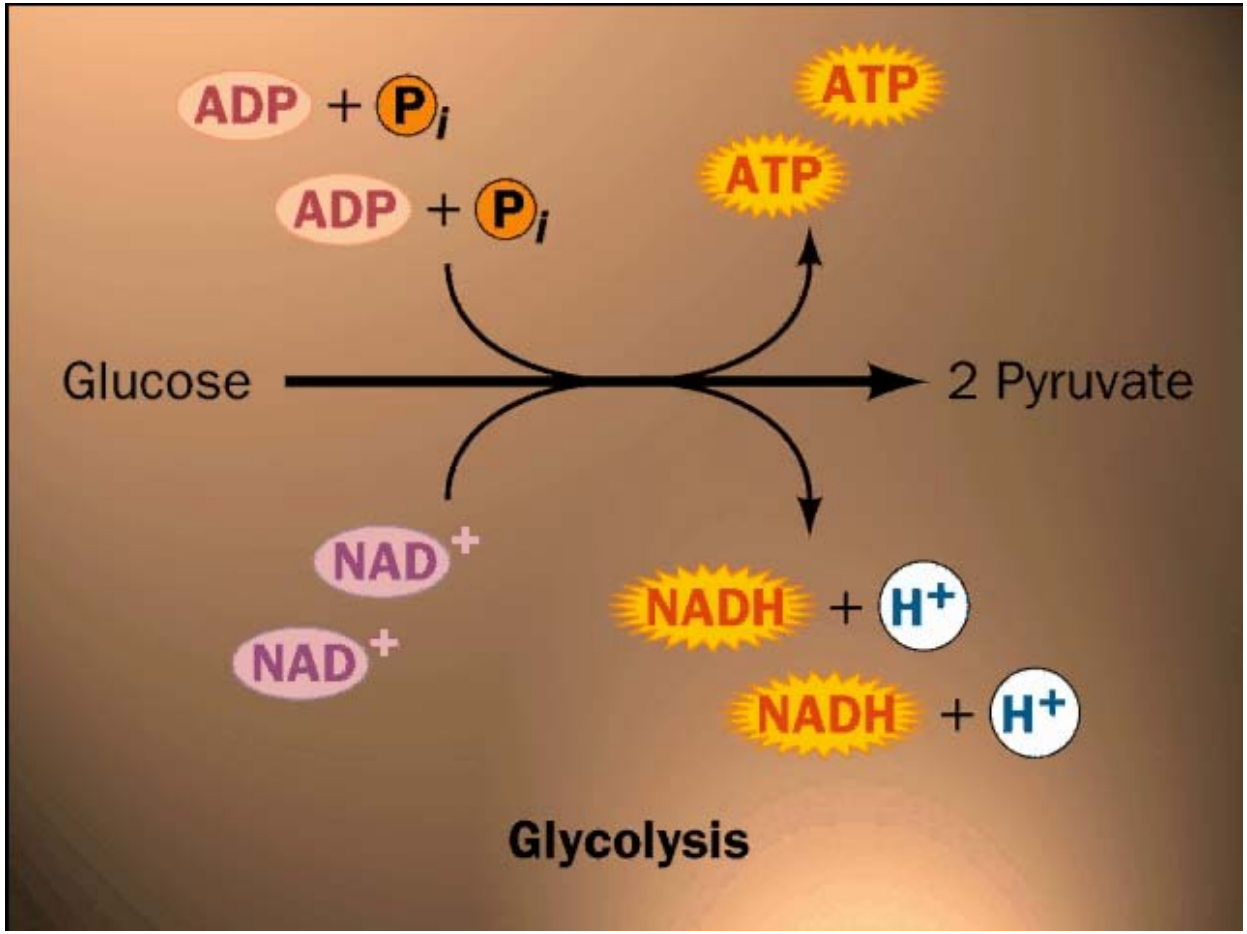
Initial reaction consume 2 ATPS to Phosphorylate both ends

The molecule is then Split into 2---3 carbon molecules that are not identical DHAP and GP



- DHAP is converted to GP
- Each GP molecule undergoes this train of reactions to produce Pyruvate
- Each GP conversion produces 2ATP and 2NADH

The First step: production of pyruvate Summary



Anaerobic Fermentation

- Energy-yielding breakdown of a nutrient molecule without net oxidation
- Drawback: produces very little energy
- Glycolysis is the principal source of the cell's ATP
  - Nets 2 ATPs
- No oxygen present to run a functional electron transport chain, therefore the energy of NADHs cannot be transferred to ATPs
- Uses 2 NADHs from glycolysis to reduce pyruvate to fermentation products

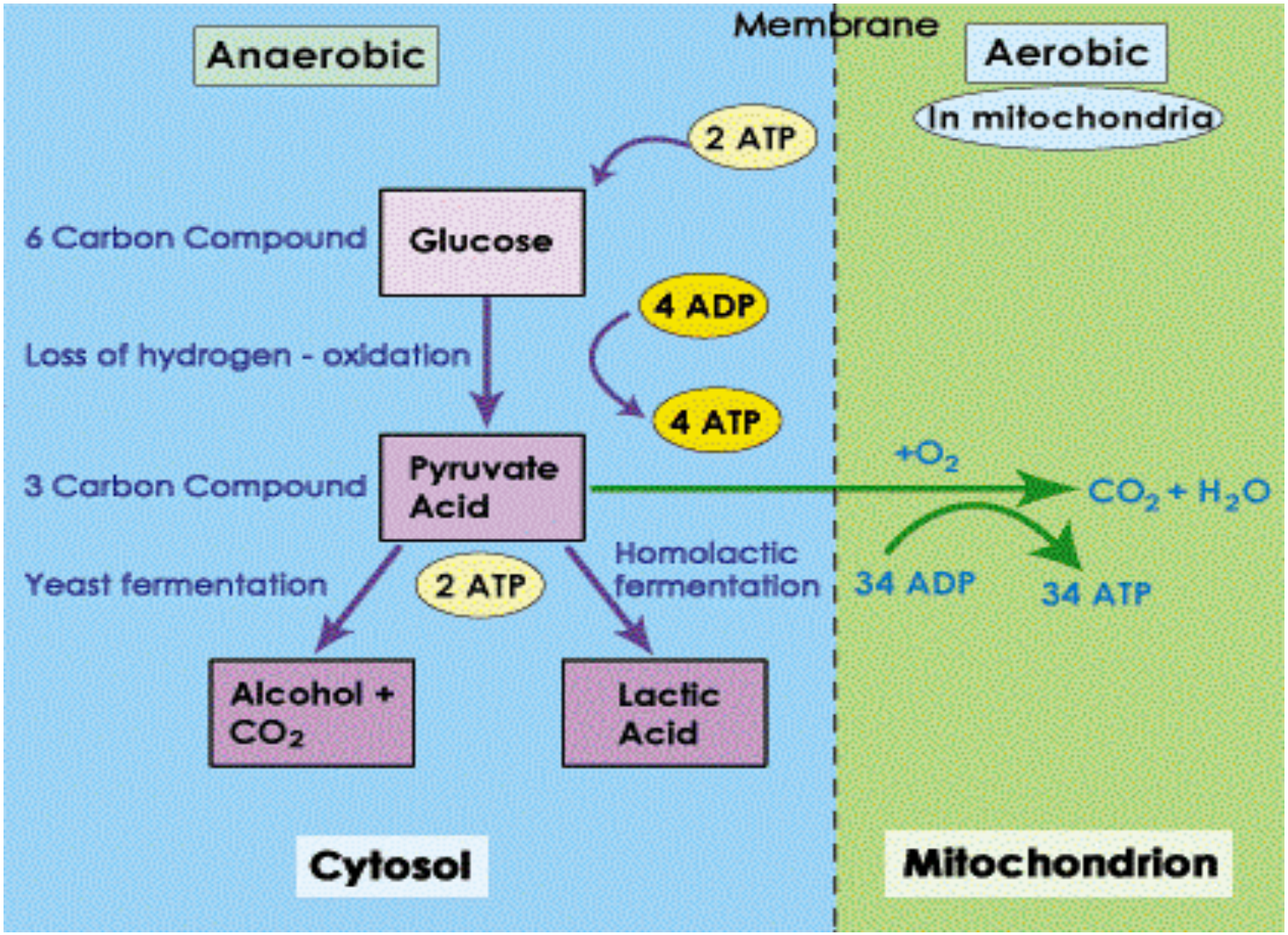
Glycolysis provides input for Krebs Cycle (Citric Acid cycle)

- The pyruvates produced in glycolysis are rapidly transported to the mitochondria where they are converted to CO_2 and acetyl CoA which is oxidized to CO_2 and H_2O in the Krebs Cycle

- (details in subsequent lecture)

In the absence of oxygen

- Glycolysis is the principal source of the cell's ATP
- The pyruvates and NADHs produced from glycolysis stay in the cytosol and are processed by anaerobic fermentation
- Can choose one of two pathways
  - Lactic Acid Fermentation
  - Alcohol Fermentation


Anaerobic
Membrane
Aerobic
In mitochondria
2 ATP
6 Carbon Compound
Glucose
4 ADP
Loss of hydrogen - oxidation
4 ATP
3 Carbon Compound
Pyruvate Acid
+O2
CO2 + H2O
Homolactic fermentation
Yeast fermentation
2 ATP
34 ADP
34 ATP
Alcohol + CO2
Lactic Acid
Cytosol
Mitochondrion

Anaerobic Fermentation

- Fermentation products: alcohol, lactate, acetic acid or other simple products
- Most energy remains in fermentation products
- The production of fermentation end products is necessary because the NADH molecule must be re-oxidized so that it can function in the next round of glycolysis

Examples of fermentation end products

- *Sacchromyces*:
  - ethanol and carbon dioxide
- *Streptococcus* and *Lactobacillus*:
  - lactic acid
- *Propoinibacterium*:
  - proprionic acid, acetic acid, and carbon dioxide
- *E. coli*:
  - acetic acid, lactic acid, succinic acid, ethanol+carbon dioxide, and hydrogen.

Anaerobic Fermentation

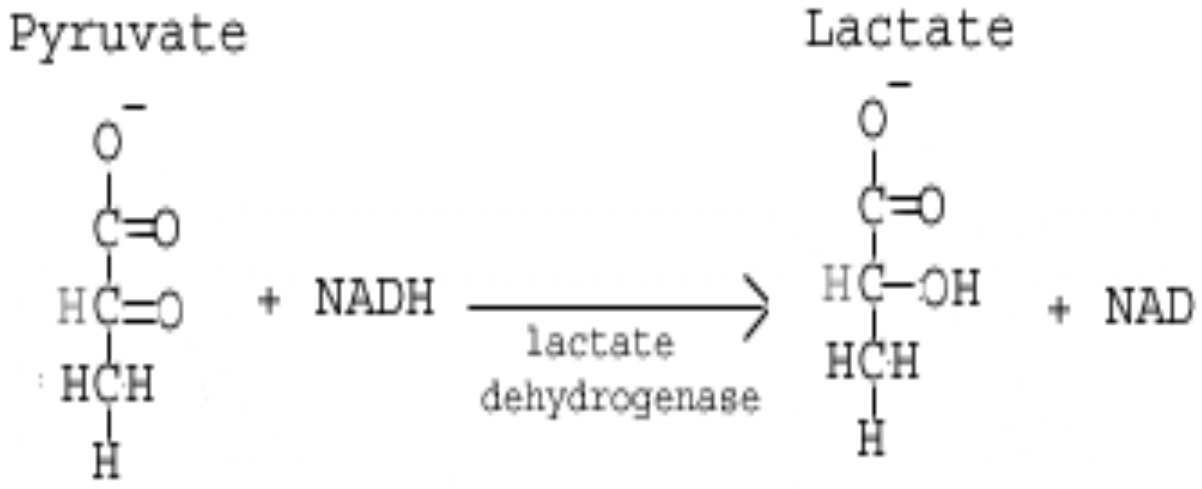
- Occurs in many anaerobic organisms, which do not use oxygen to grow
- Occurs in animal tissues, such as skeletal muscle when oxygen is limited
- Is commercially used to make alcoholic beverages (beer, wine, sake) and to preserve food (yogurt)

Lactic Acid fermentation

- Occurs in animal cells
- Only type of fermentation available to humans
- Occurs when the ATP needs of a cell outpace the oxygen supply (such as in strenuous exercise), cells can only use fermentation for ATP production
- Pyruvate is converted into lactate, regenerating NAD^+, allowing glycolysis to continue

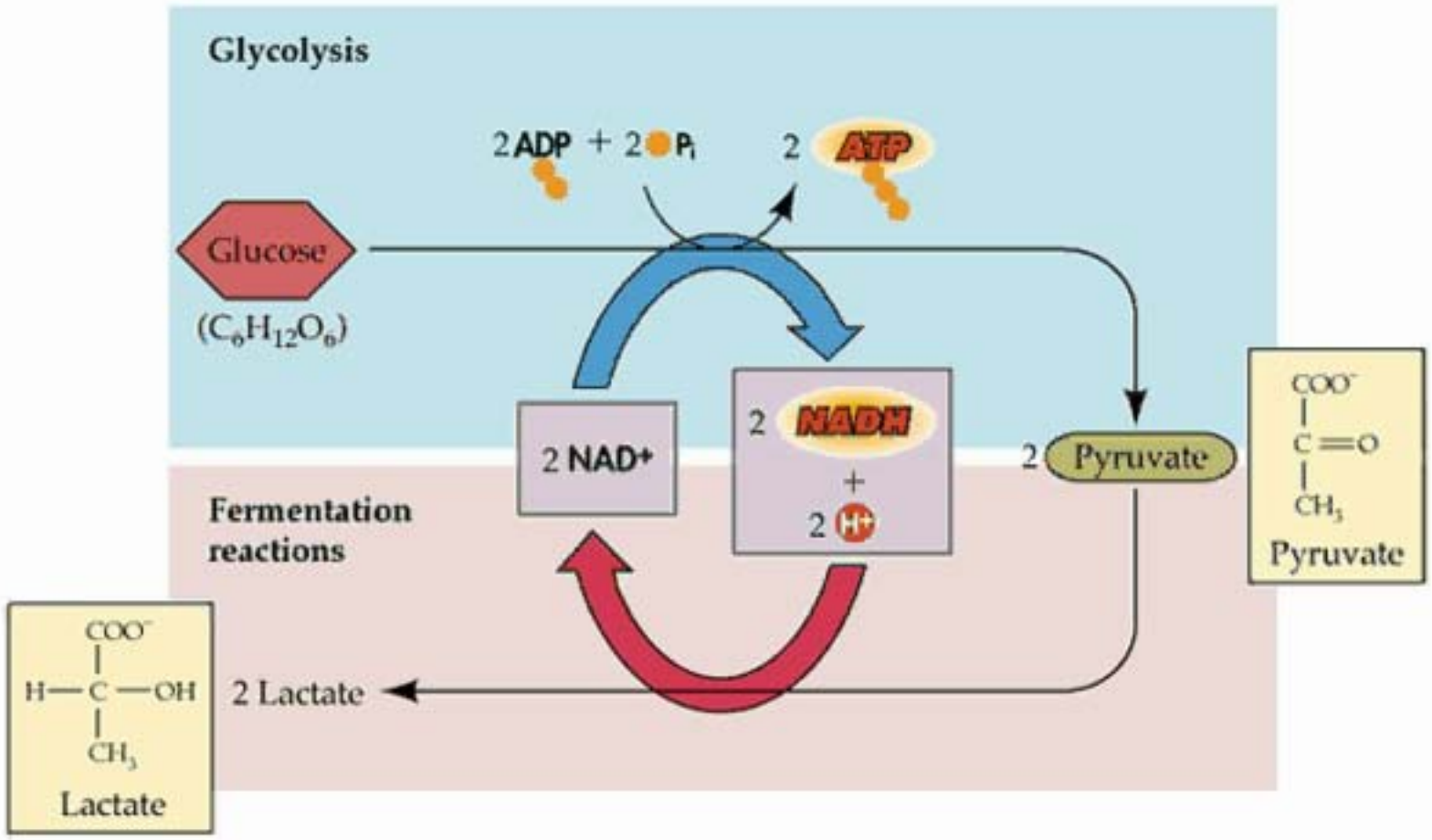
Lactic Acid fermentation

- Pyruvate is converted into lactate by **lactate dehydrogenase**
  - The hydrogen from the NADH molecule is transferred to pyruvate forming lactate



Lactic Acid fermentation

- From the lactate product, lactic acid can be formed,
  - The build up of lactic acid is what causes the muscle fatigue that accompanies strenuous workouts when oxygen becomes deficient
  - Homolactic fermentation
  - Only fermentation in humans
- Alcohol dehydrogenase is missing in humans that is why we get lactic acid build up. Instead humans use lactate dehydrogenase to regenerate ATP.

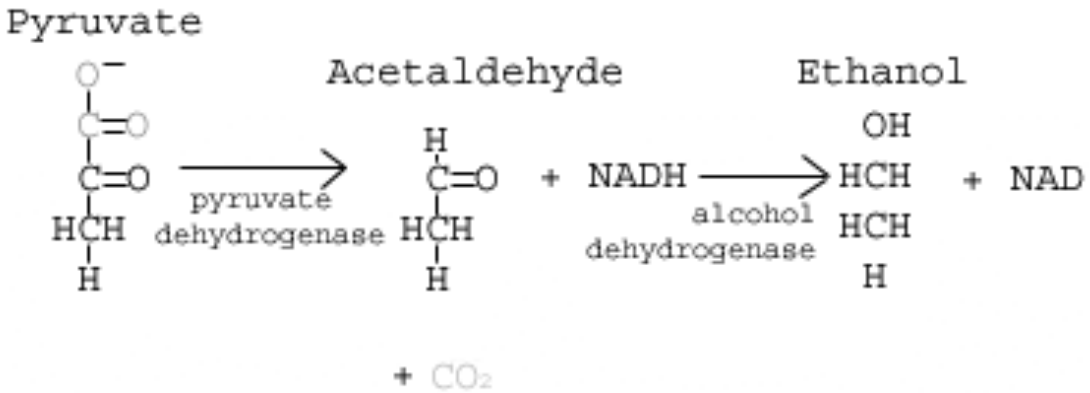

Glycolysis
2 ADP + 2 Pi
2 ATP
Glucose
(C6H12O6)
2 NAD+
2 NADH
+
2 H+
2 Pyruvate
COO⁻
C=O
CH3
Pyruvate
Fermentation reactions
COO⁻
H—C—OH
CH3
Lactate
2 Lactate

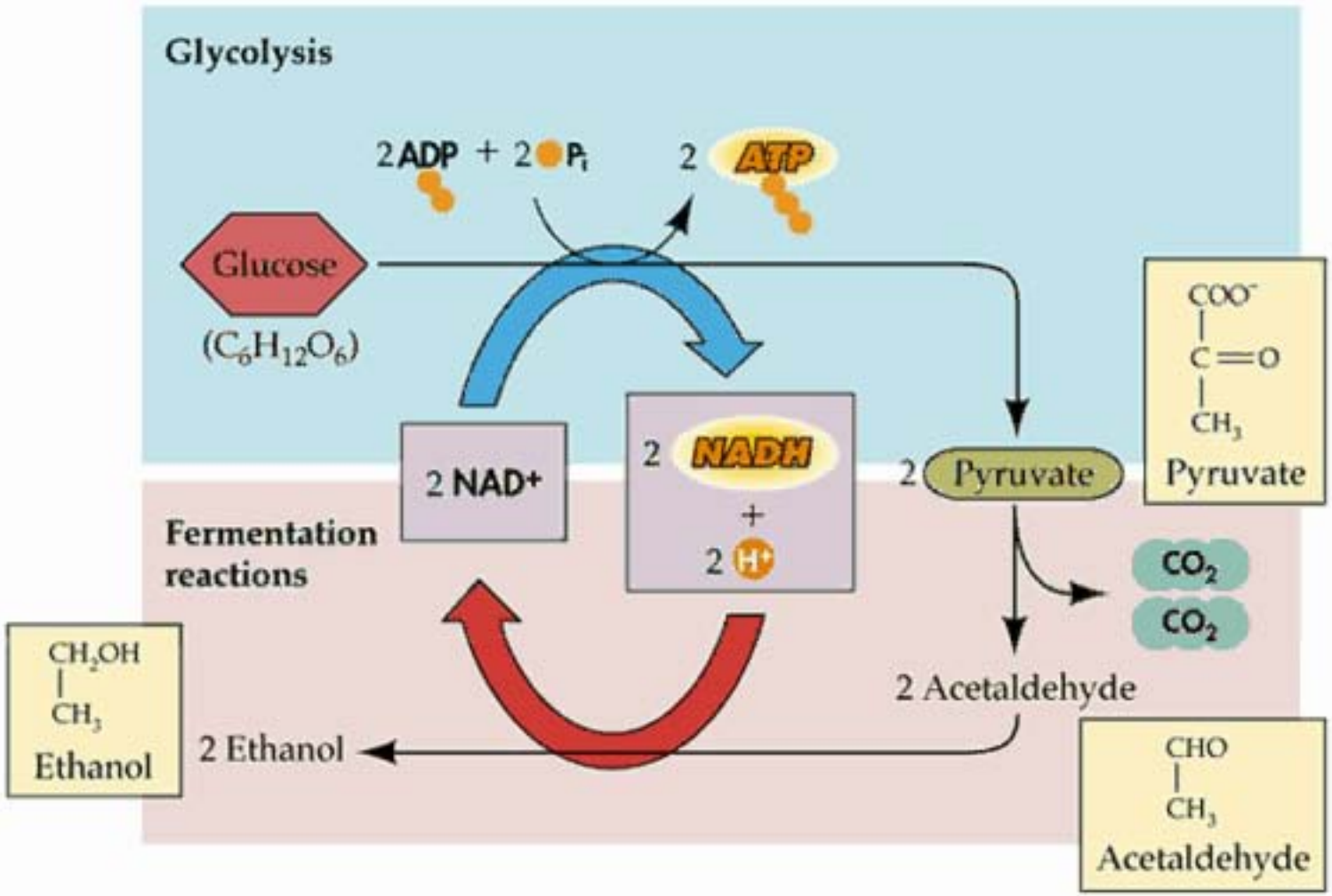
Alcoholic Fermentation

- Occurs in yeast
- Important in wine and beer industry
- Pyruvate is converted into alcohol in a two step process
  - Pyruvate to Acetaldehyde by pyruvate dehydrogenase, releasing CO_2
  - Acetaldehyde to ethanol by alcohol dehydrogenase, releasing NAD^+

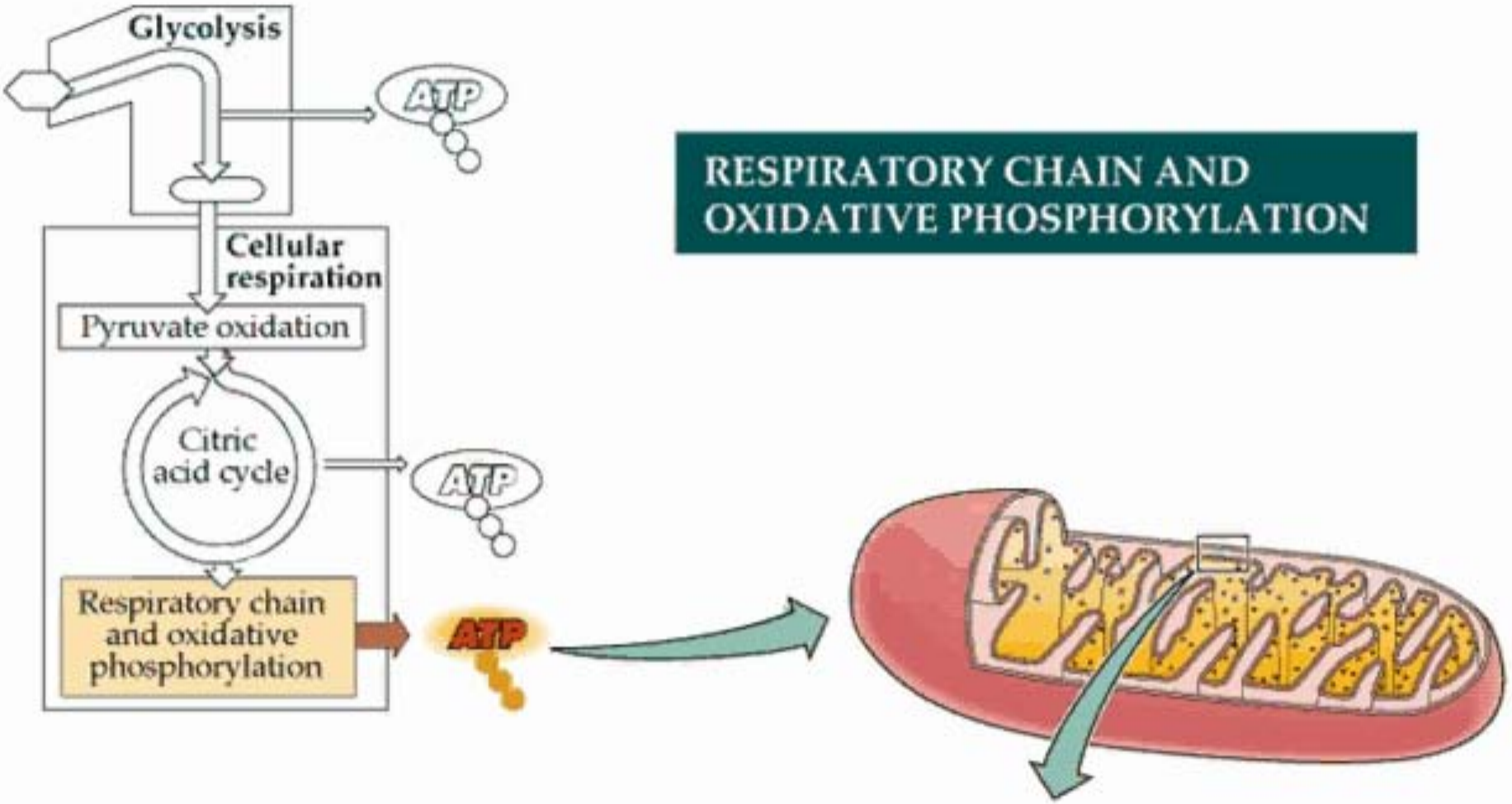
Alcoholic Fermentation

- Pyruvate is converted to Acetaldehyde by pyruvate dehydrogenase
  - A CO_2 molecule is removed from pyruvate to yield acetylaldehyde
- Acetaldehyde is converted to ethanol by alcohol dehydrogenase
  - The hydrogen from the NADH molecule is transferred to acetylaldehyde to yield NAD and ethanol




Glycolysis
2 ADP + 2 P_i
2 ATP
Glucose
$(C_6H_{12}O_6)$
2 NAD+
2 NADH
+
2 H^+
2 Pyruvate
COO^-
C=O
CH_3
Pyruvate
Fermentation reactions
CO_2
CO_2
2 Acetaldehyde
CH_2OH
CH_3
Ethanol
2 Ethanol
CHO
CH_3
Acetaldehyde

RESPIRATORY CHAIN AND OXIDATIVE PHOSPHORYLATION



Conclusion

- Cell will use anaerobic fermentation when oxygen is deficient in order to continue producing energy
- Anaerobic fermentation is less efficient, and can produce a multitude of products depending on the organism