# BIOCHEMISTRY

# Glycolysis

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# Chapter Description

- Overview

  This chapter is related to carbohydrate catabolism. It leads to ATP production at substrate level as well as eventually by oxidative phosphorylation. Some understanding on aerobic and anaerobic pathways been included.

- Expected Outcomes

  You should be able to understand glycolytic pathway as a whole and its ubiquitous importance in living organism.

- Other related Information

  Some relevant questions been provided for improving your understanding of the topic. You are expected to search for external sources for information to adequately answer the questions. All pictures and figures within this chapter categorized as creative commons for the purpose of education only.


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http://ocw.ump.edu.my/course/view.php?id=485

# Glycolysis (Embden Meyerhof Pathway):

# ESSENTIAL KNOWLEDGE

## A. Definition:

1. Glycolysis means oxidation of glucose to give pyruvate (in the presence of oxygen) or lactate (in the absence of oxygen).

## B. Site:

cytoplasm of all tissue cells, but it is of physiological importance in:

1. Tissues with no mitochondria: mature RBCs, cornea and lens.
2. Tissues with few mitochondria: Testis, leucocytes, medulla of the kidney, retina, skin and gastrointestinal tract.
3. Tissues undergo frequent oxygen lack: skeletal muscles especially during exercise.

## C. Steps:

**Stages of glycolysis**

**1. Stage one (the energy requiring stage):**

a) One molecule of glucose is converted into two molecules of of glyceraldehyde-3-phosphate

b) These steps requires 2 molecules of ATP (energy loss)

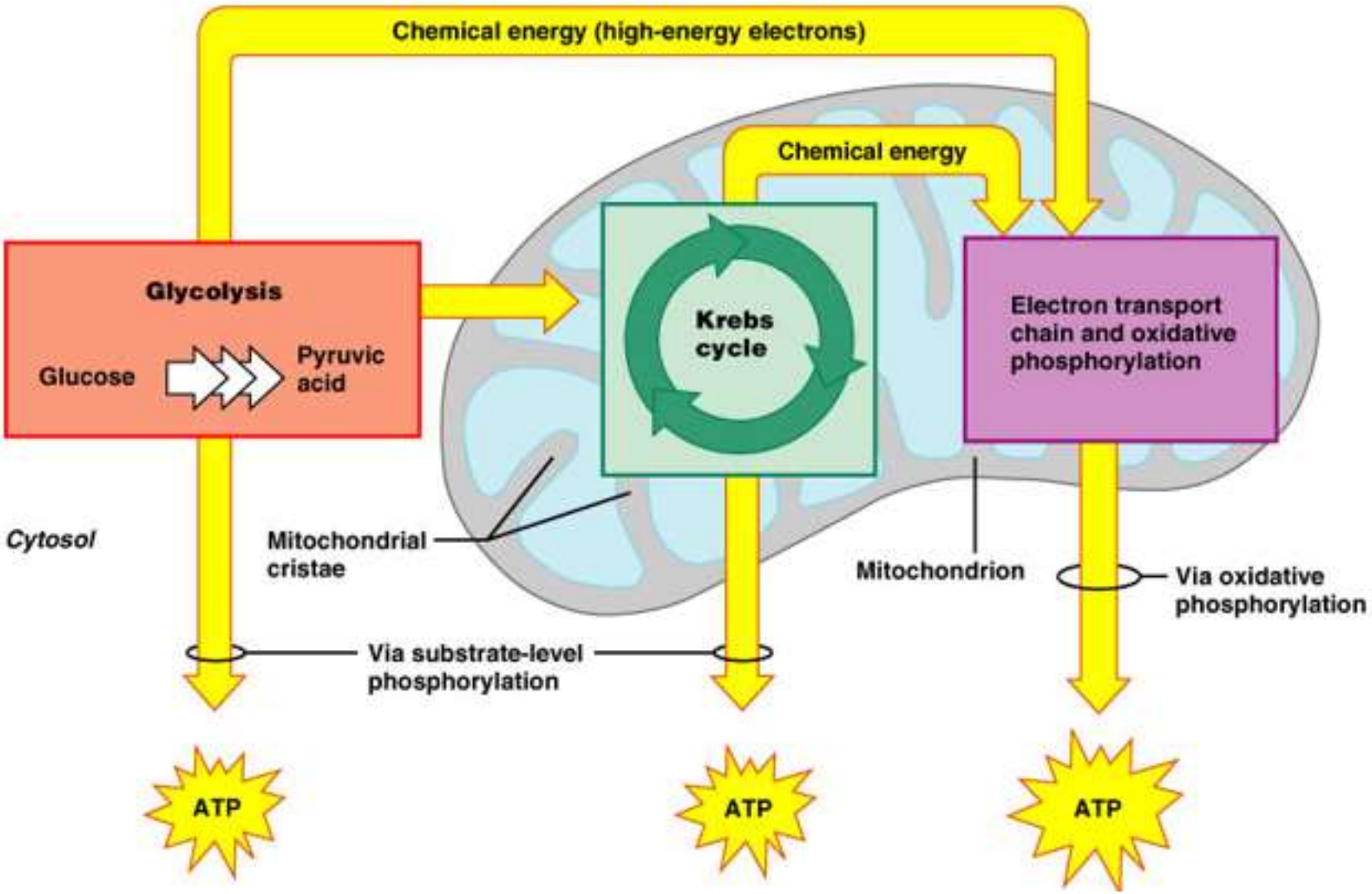
**2. Stage two (the energy producing stage):**

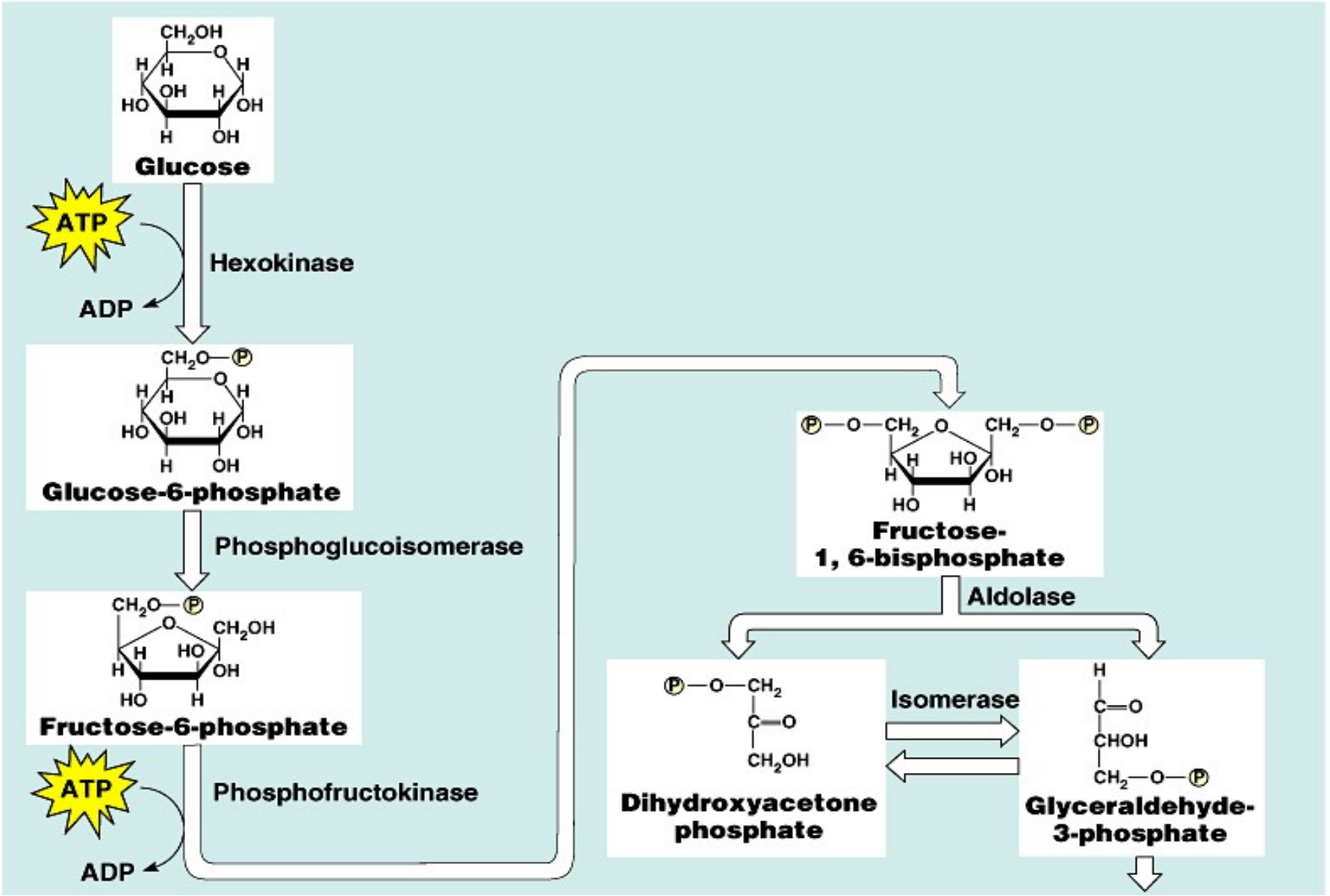
a) The 2 molecules of glyceraldehyde-3-phosphate are converted into pyruvate (aerobic glycolysis) or lactate (anaerobic glycolysis).

b) These steps produce ATP molecules (energy production).

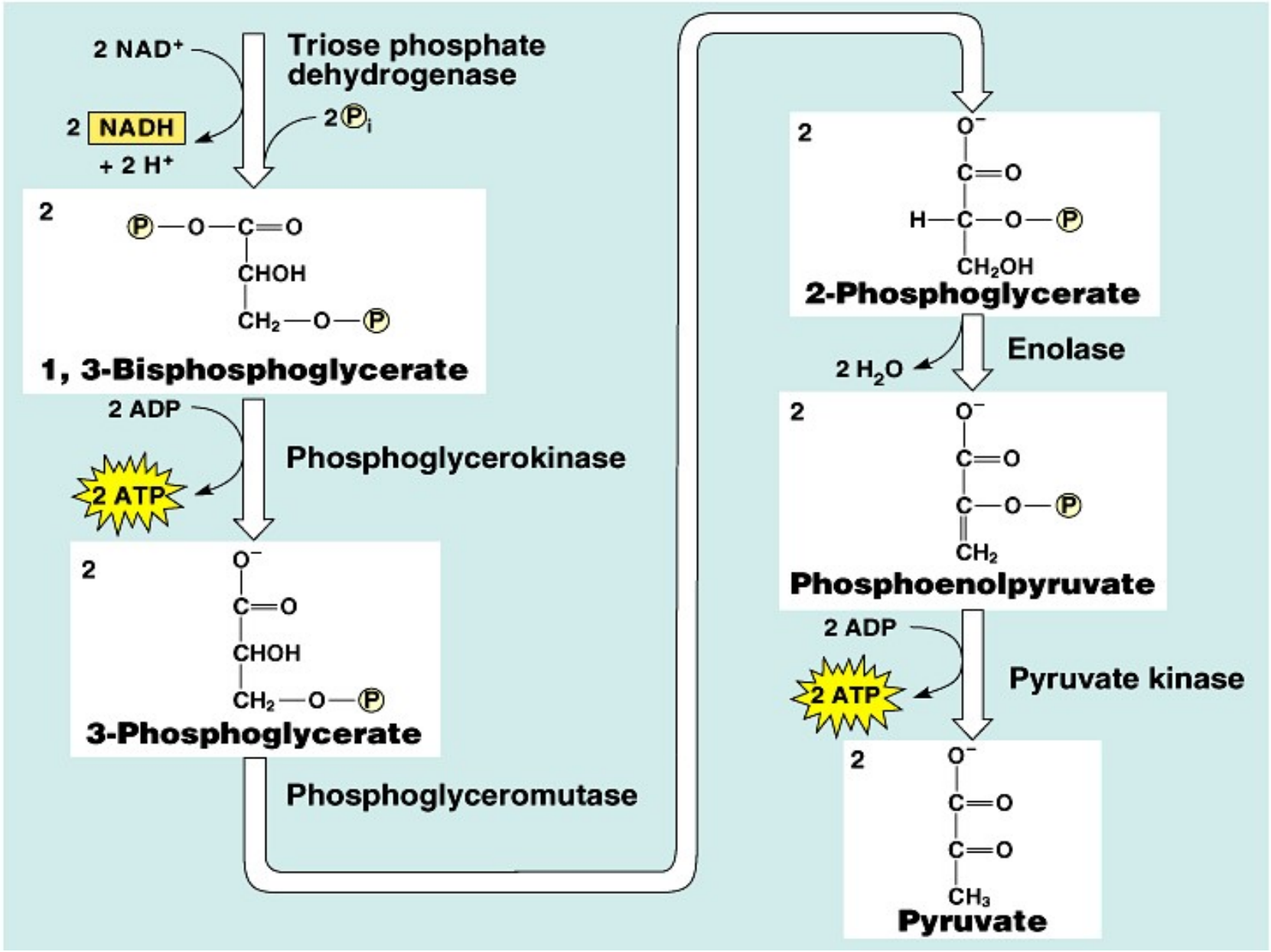
## D. Energy (ATP) production of glycolysis:

**Nett ATP production = ATP produced - ATP utilized**


Chemical energy (high-energy electrons)
Chemical energy
Glycolysis
Glucose
Pyruvic acid
Krebs cycle
Electron transport chain and oxidative phosphorylation
Cytosol
Mitochondrial cristae
Mitochondrion
Via oxidative phosphorylation
Via substrate-level phosphorylation
ATP
ATP
ATP




# Energy Investment Phase (steps 1-5)




## Energy-Payoff Phase (Steps 6-10)

# Fate of pyruvate under aerobic conditions

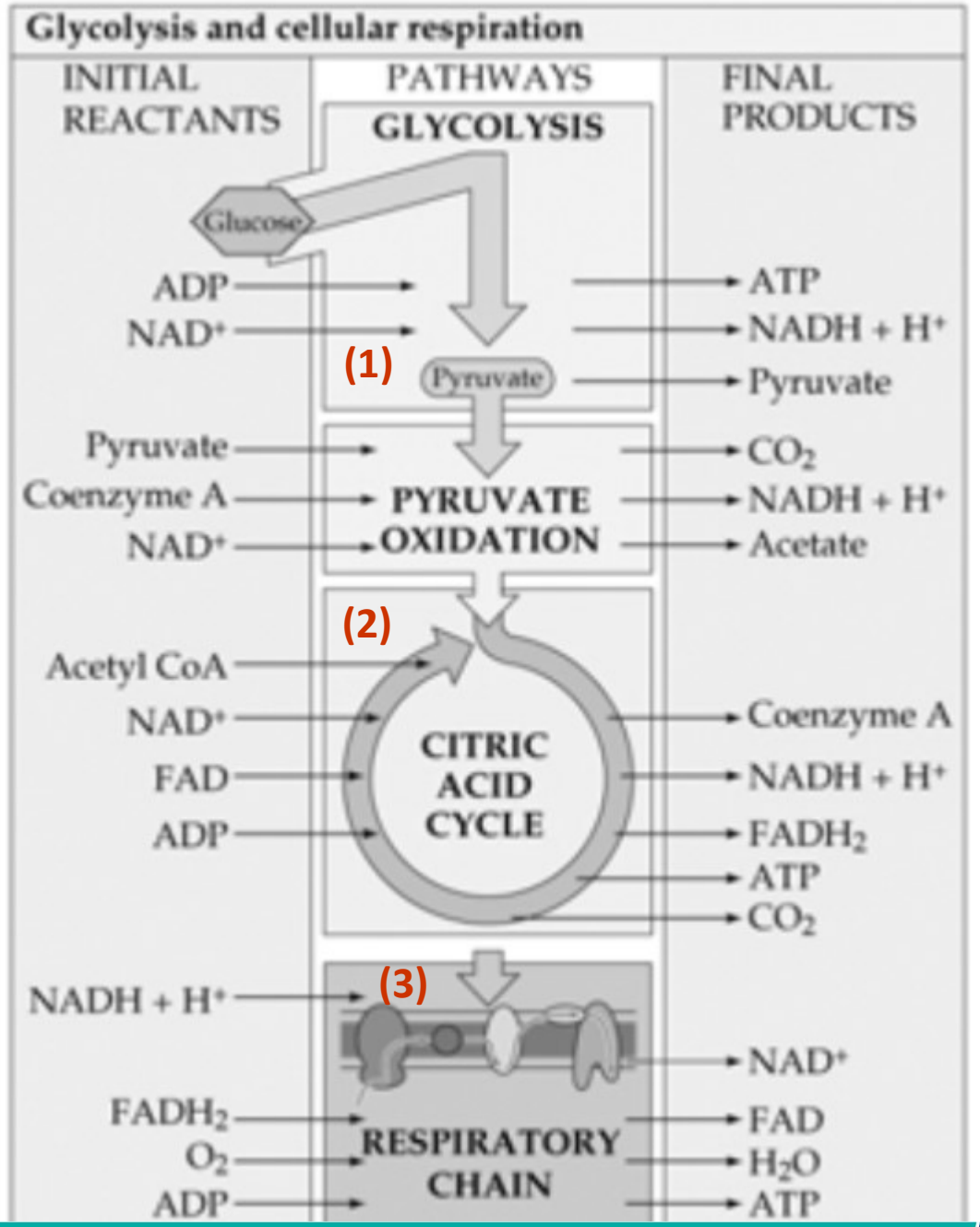
- Pyruvate oxidation and the citric acid cycle produce $CO_2$ and hydrogen atoms carried by NADH and $FADH_2$.

- The respiratory chain combines the hydrogens with $O_2$, releasing enough energy for ATP synthesis.

•Remember there is also anaerobic

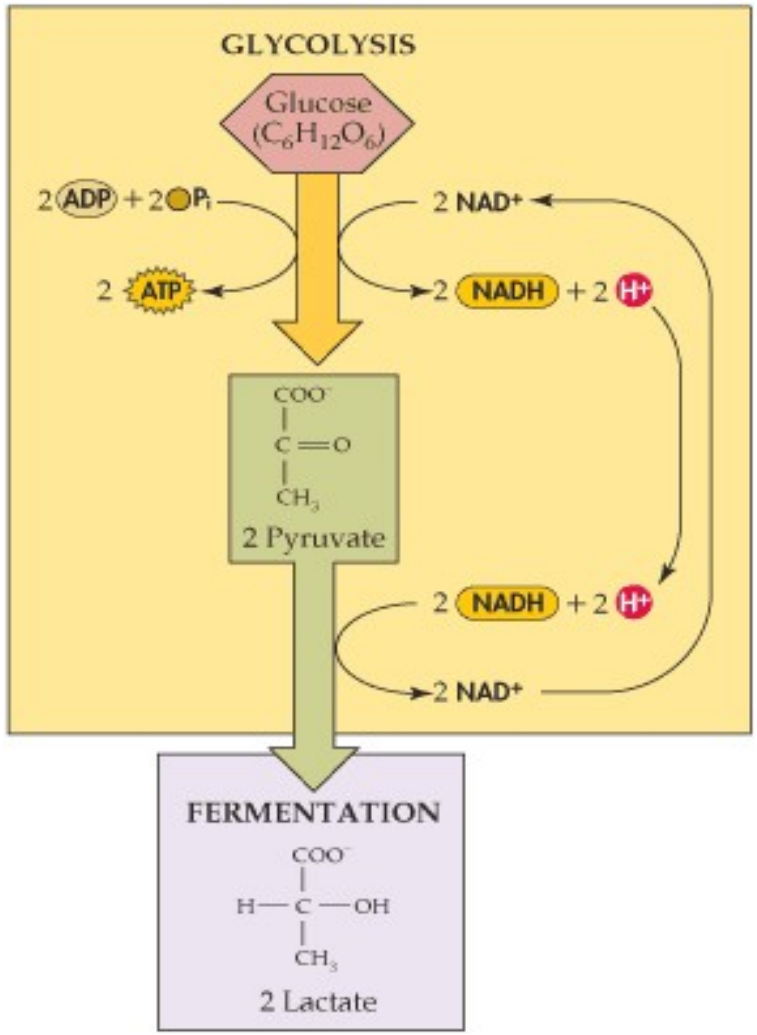
•Depends whether there is oxygen supply or lack of it

- The overall pathways when oxygen is present



# Fate of pyruvate under anaerobic conditions

- In some cells under anaerobic conditions, pyruvate can be reduced by NADH to form lactate and regenerate the NAD needed to sustain glycolysis.



# Fermentation: ATP from Glucose, without $O_2$

- These pathways partly oxidize glucose and generate energy-containing products (ATP) via glycolysis.

# Fermentation: Summary

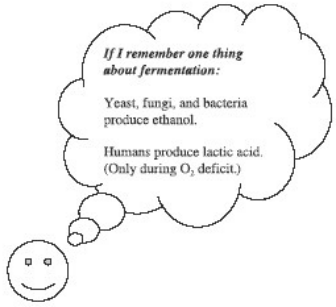
- Fermentation reactions anaerobically oxidize the NADH + $H^+$ produced in glycolysis and reduce pyruvate to lactic acid (in active skeletal muscles) or ethanol (in yeast). In this process $NAD^+$ is regenerated - $NAD^+$ is required in glycolysis.

# Energy production of glycolysis:

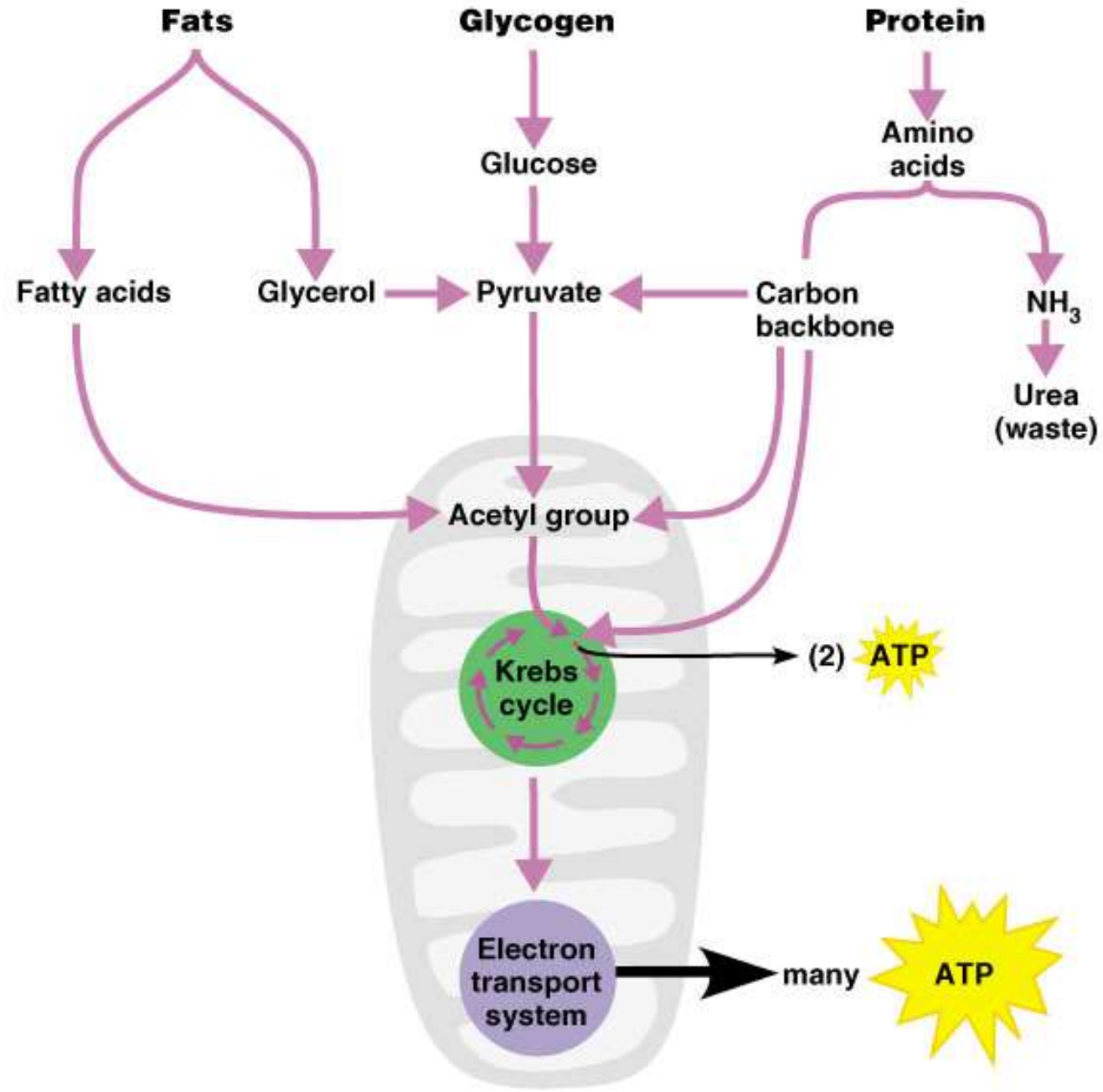
| | ATP produced | ATP utilized | Net energy |
|---|---|---|---|
| **In absence of oxygen (anaerobic glycolysis)** | 4 ATP (Substrate level phosphorylation) 2ATP from 1,3 BPG. 2ATP from phosphoenol pyruvate | 2ATP From glucose to glucose -6-p. From fructose -6-p to fructose 1,6 p. | **2 ATP** |
| **In presence of oxygen (aerobic glycolysis)** | 4 ATP (substrate level phosphorylation) 2ATP from 1,3 BPG. 2ATP from phosphoenol pyruvate. + 4ATP or 6ATP (from oxidation of 2 NADH + H in mitochondria). | 2ATP -From glucose to glucose -6-p. From fructose -6-p to fructose 1,6 p. | **6 ATP Or 8 ATP** |

# Differences between aerobic and anaerobic glycolysis:

| Inference | Aerobic | Anaerobic |
|---|---|---|
| End product | Pyruvate | Lactate |
| Energy | 6 or 8 ATP | 2 ATP |
| Regeneration of $NAD^+$ | Through respiration chain in mitochondria | Through Lactate formation |
| Availability to TCA in mitochondria | Available and 2 Pyruvate can oxidize to give 30 ATP | Not available as lactate is cytoplasmic substrate |



# Other Metabolic Pathways



# Special features of glycolysis in RBCs:

1. **Mature RBCs contain no mitochondria, thus:**
   a) **They depend only upon glycolysis for energy production (=2 ATP).**
   b) **Lactate is always the end product.**

2. **Glucose uptake by RBCs is independent on insulin hormone.**

3. **Reduction of met-hemoglobin: Glycolysis produces NADH+H+, which is used for reduction of met-hemoglobin in red cells.**

# All the importance (functions) of glycolysis:

**1. Energy production:**

a) anaerobic glycolysis gives 2 ATP.

b) aerobic glycolysis gives 6 - 8 ATP.

**2. Oxygenation of tissues:**

Through formation of 2,3 bisphosphoglycerate, which decreases the affinity of Hemoglobin to oxygen.

**3. Provides important intermediates:**

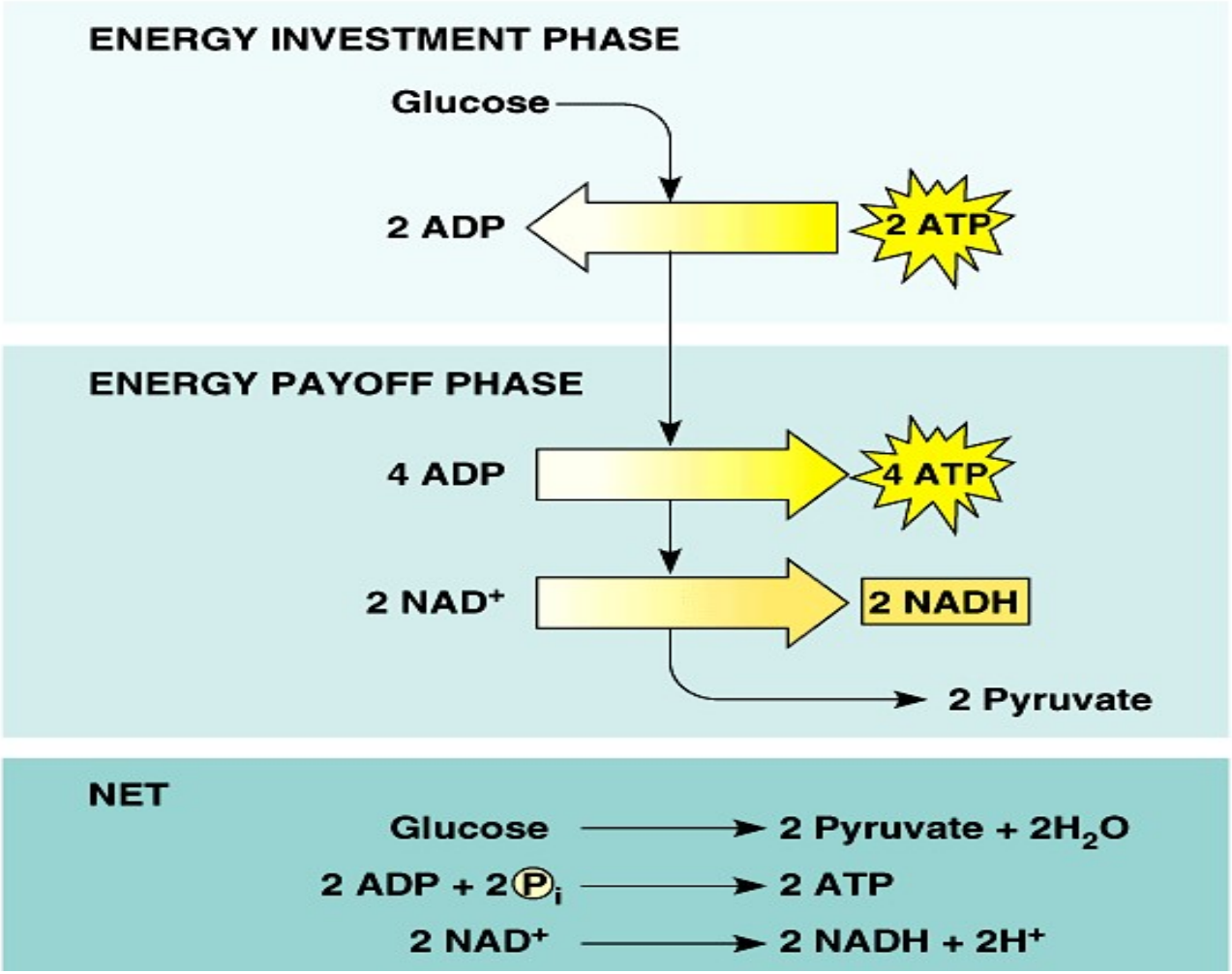
a) Dihydroxyacetone phosphate: can give glycerol-3-phosphate, which is used for synthesis of triacylglycerols and phospholipids (lipogenesis).

b) 3 Phosphoglycerate: which can be used for synthesis of amino acid serine.

c) Pyruvate: which can be used in synthesis of amino acid alanine.

4. Aerobic glycolysis provides the mitochondria with pyruvate, **which gives acetyl CoA for initial substrate to support the Krebs' cycle.**

# Economics of Biological Energy
# GLYCOLYSIS



# Summary Glycolysis: Specific tissue functions

- RBC's
  - Rely exclusively for energy
- Skeletal muscle
  - Source of energy during exercise, particularly high intensity exercise
- Adipose tissue
  - Source of glycerol-P for TG synthesis
  - Source of acetyl-CoA for FA synthesis
- Liver
  - Source of acetyl-CoA for FA synthesis
  - Source of glycerol-P for TG synthesis

# Self Assessment

1. **A 20-year old male Malaysian athlete experienced muscle fatigue during the training session for the Olympics.**
   - Name the muscle biochemicals that contributes ATP during intensive muscle training exercise
   - Describe anaerobic glycolysis during muscle exercise
   - Describe the role of the liver during intensive muscle training exercise in preventing muscle fatigue
   - Describe the preferred glucose metabolism in the **athlete's** RBC which is devoid of mitochondria

2. **Heart exclusively aerobic and has no glycogen stores. In a heart attack or coronary blockage** (Severe ischemia in heart) **:**
   - **what changes do you expect to happen in heart glycolysis ?**
   - **what is the role of Heart Lactate Dehydrogenase (LDH) ?**

# References: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