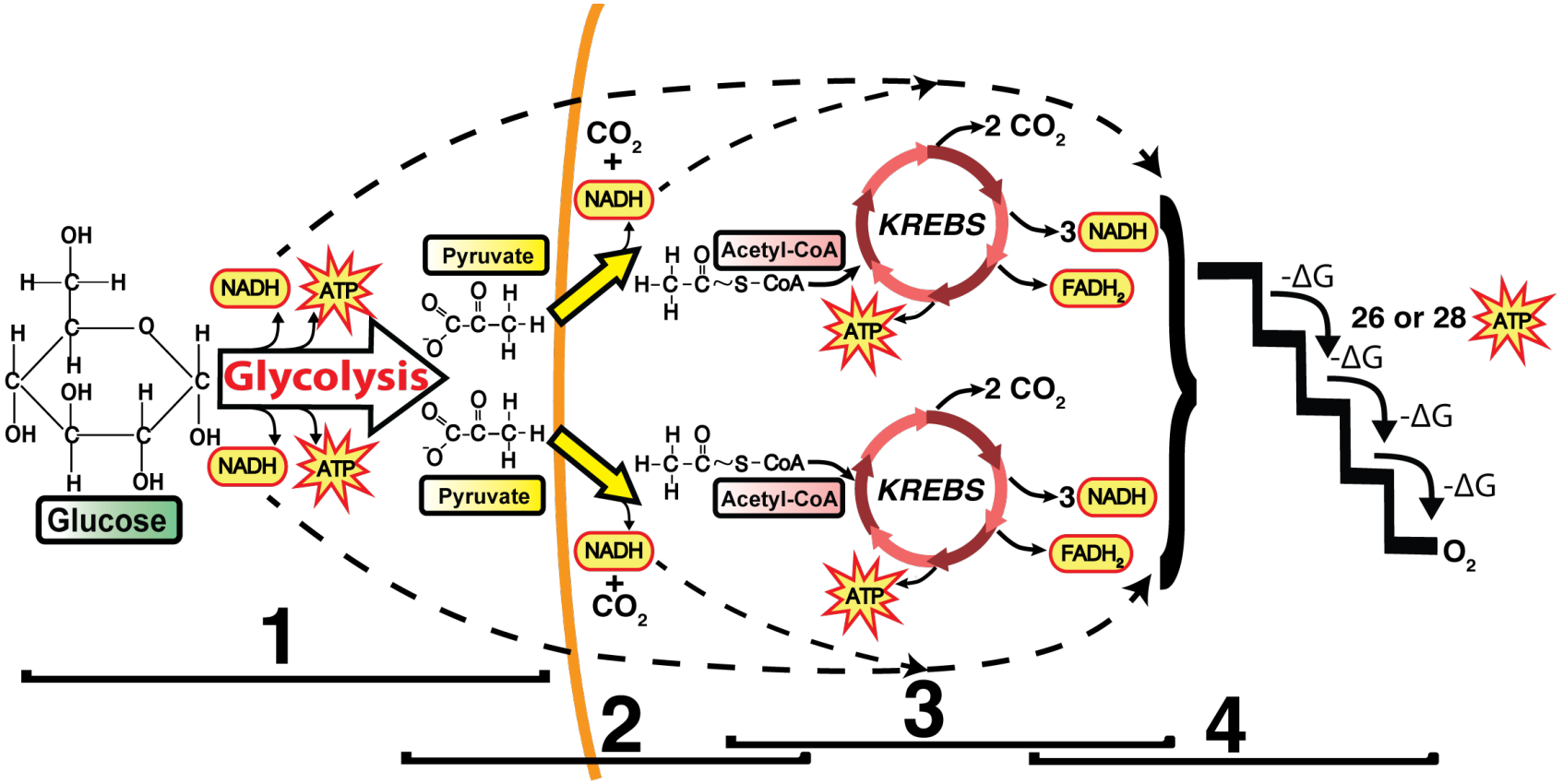
# Cellular Respiration:

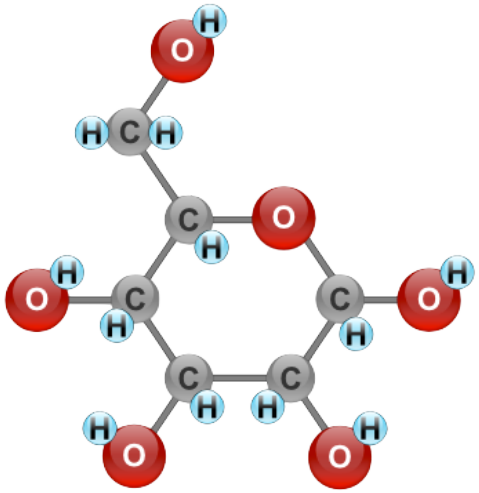
*(goal is to be able to explain this!)*



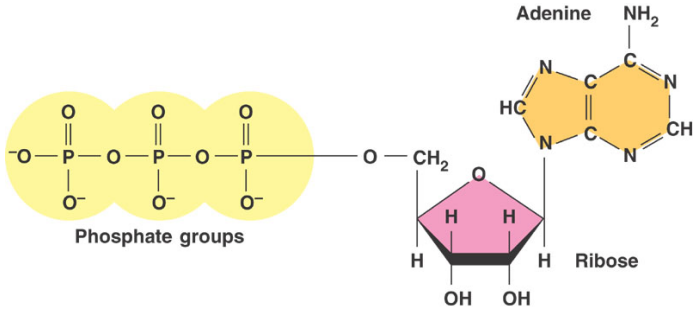
# Part 1

Overview

# What it's all about…



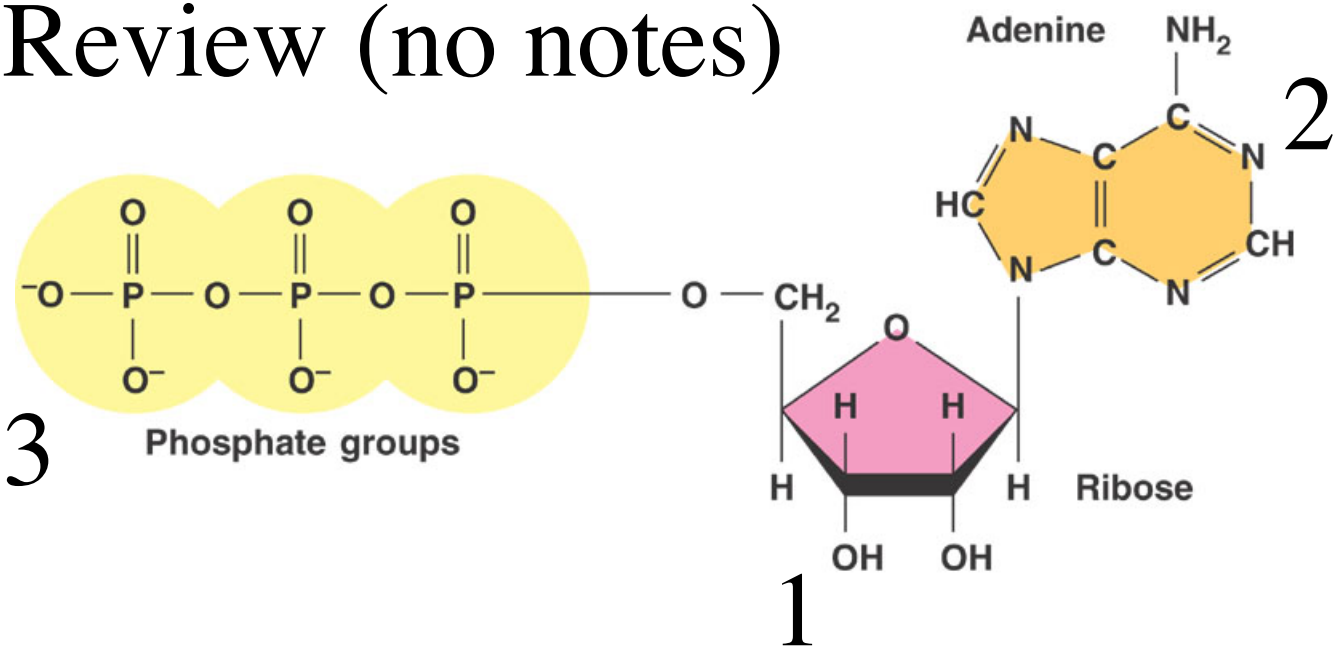
**Cellular Respiration**




1 glucose

~ 36 ATP

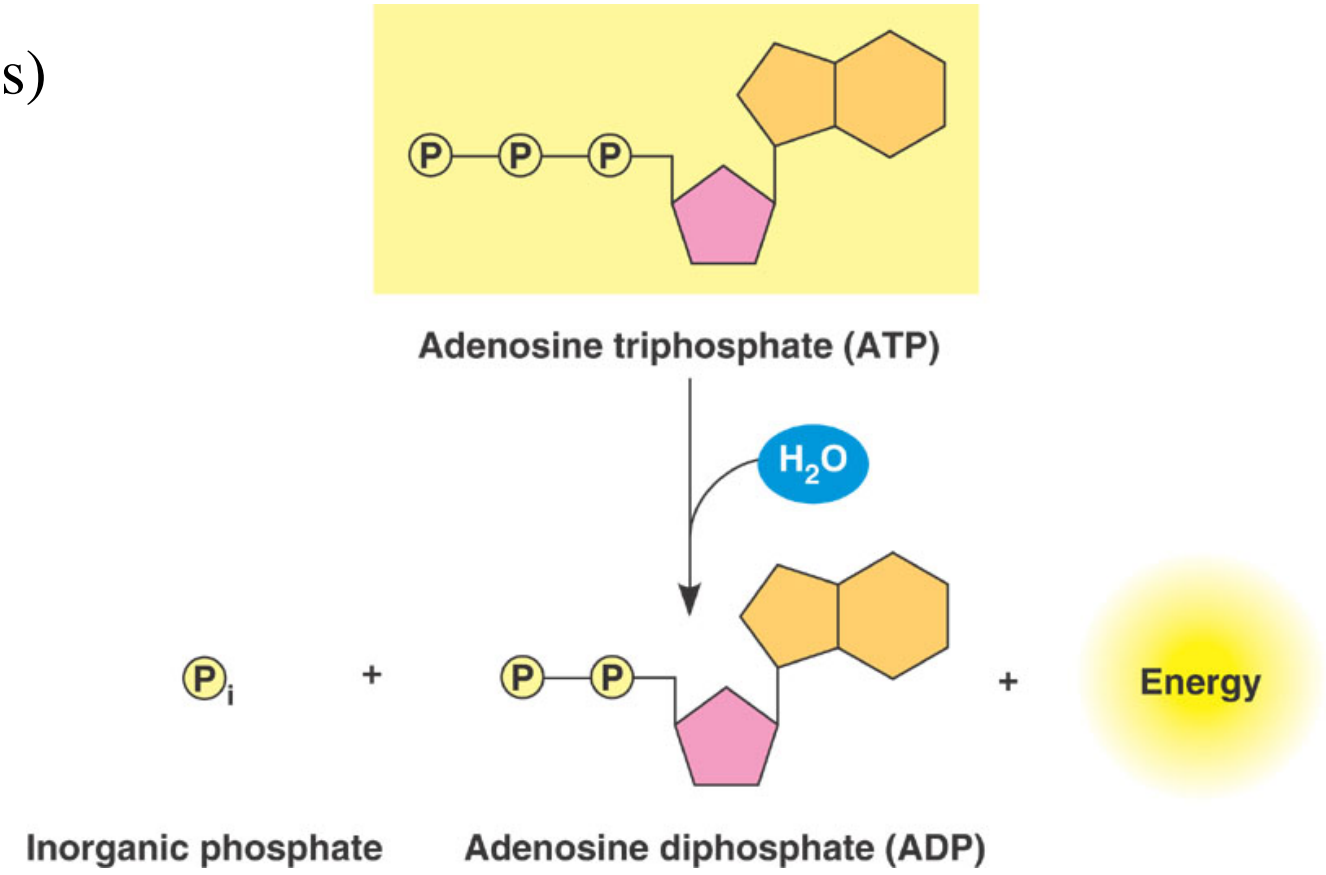
# ATP Review (no notes)




1. **a**denosine **t**ri-**p**hosphate
2. It's a *nucleotide* (monomer of nucleic acids)

# Removing one phosphate…

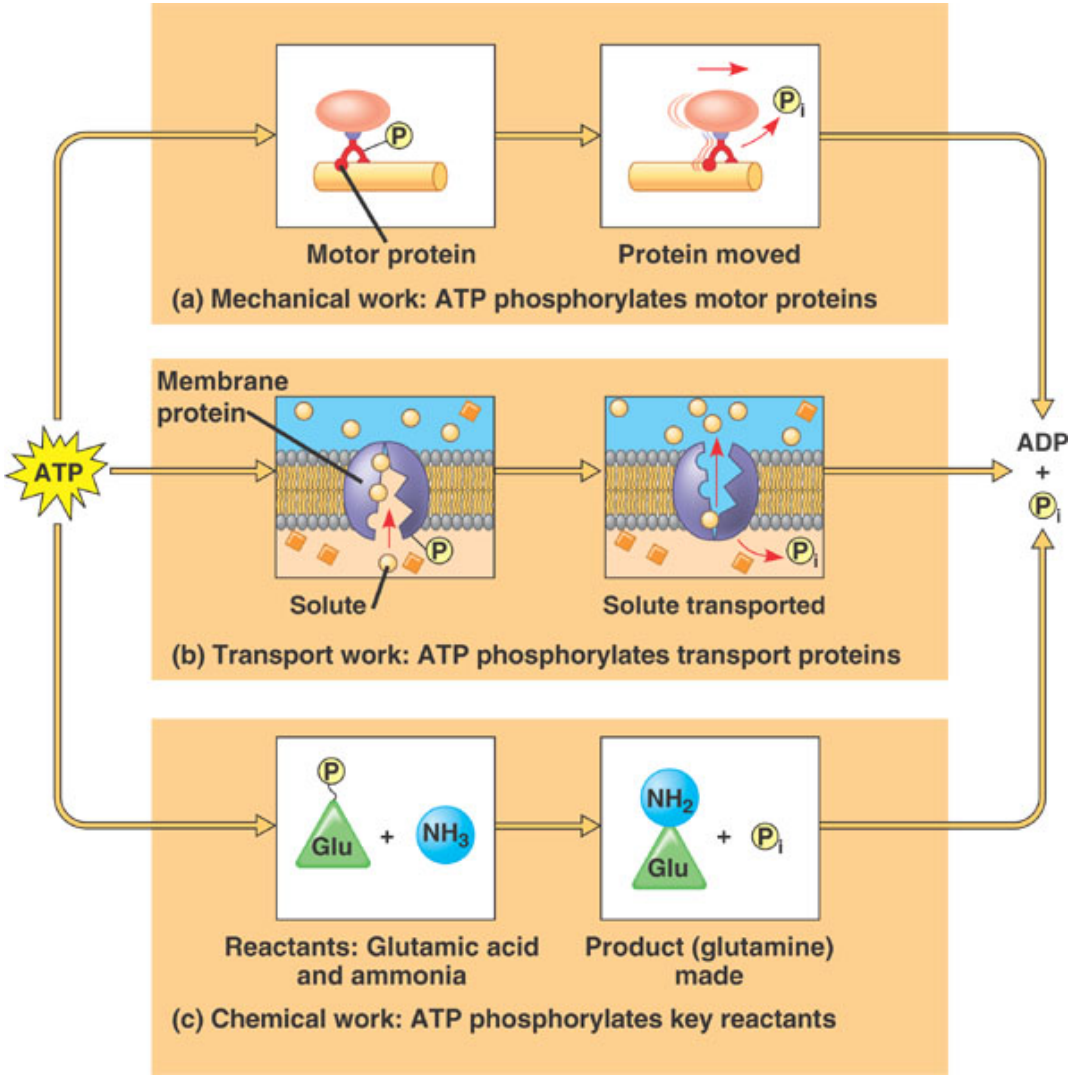
(no notes)




Creates ADP, and $P_i$ (inorganic phosphate), and makes **energy available to the cell**

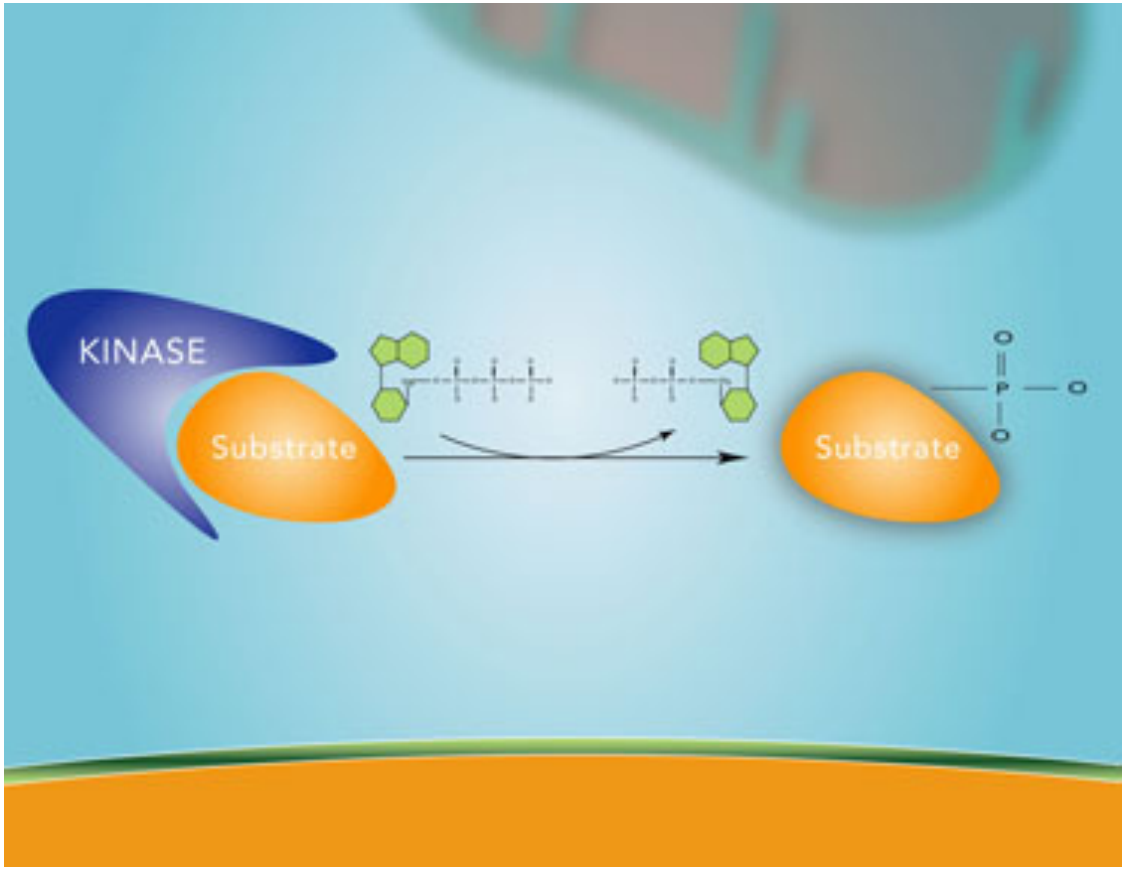
# …Releasing the perfect quantity of energy for cellular work

(no notes)



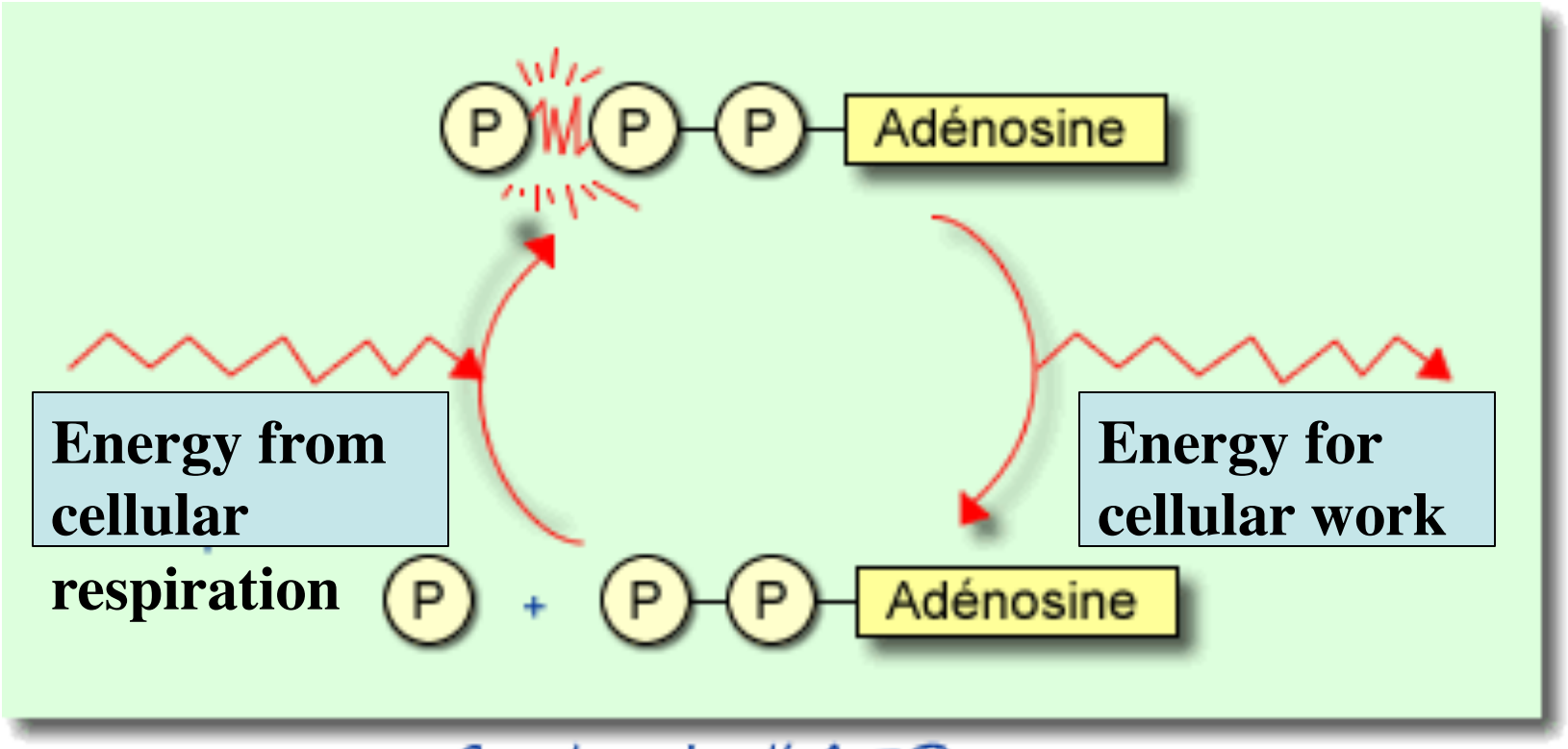
(no notes)

# ATP often works by *phosphorylation*




- An enzyme transfers a phosphate from ATP to another molecule, energizing that molecule for cellular work.

# ATP - ADP cycle



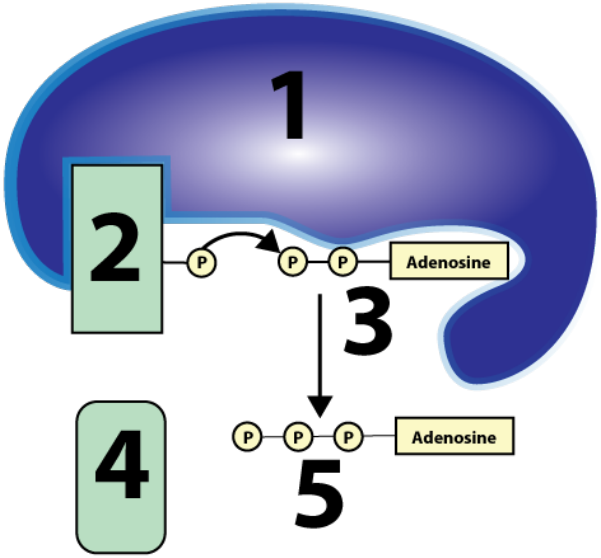

Cycle de l'ATP

# Cellular Respiration abbreviations

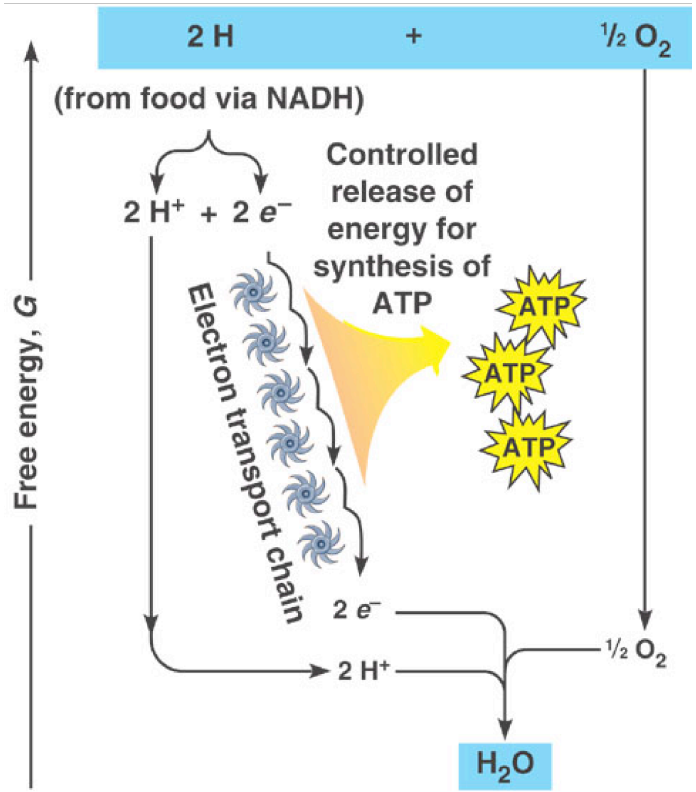
- $e^-$ : an electron
- $H^+$: a proton
- ~ : about
- REDOX: oxidation/reduction
- ETC: electron transport chain

# Two ways to make ATP

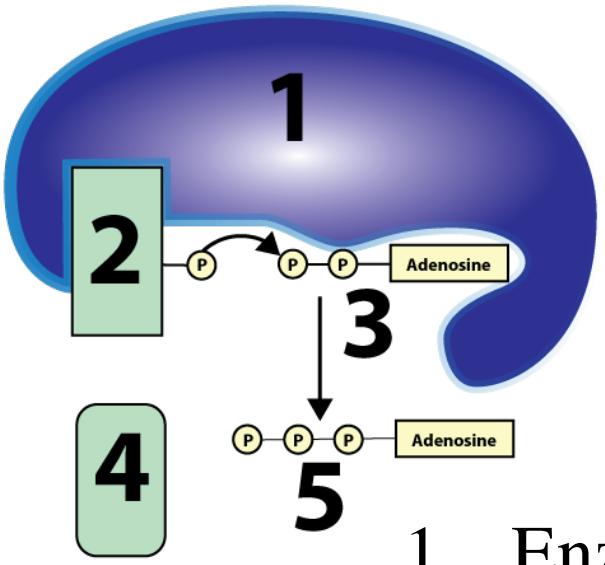
- Substrate Level Phosphorylation




- Oxidative Phosphorylation



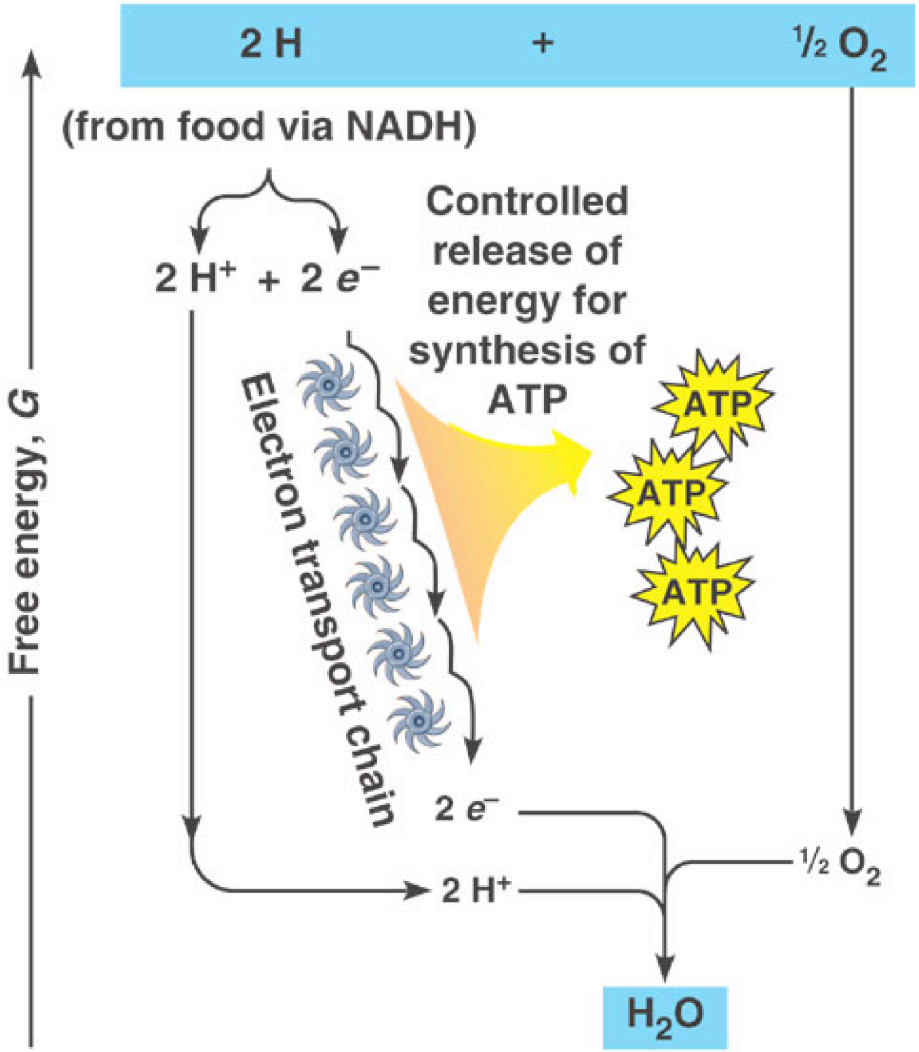
# Substrate-level phosphorylation




- Enzymes transfer a phosphate group from a substrate onto ADP (making ATP)
- Makes ~ 1/8 of the ATP in resp.

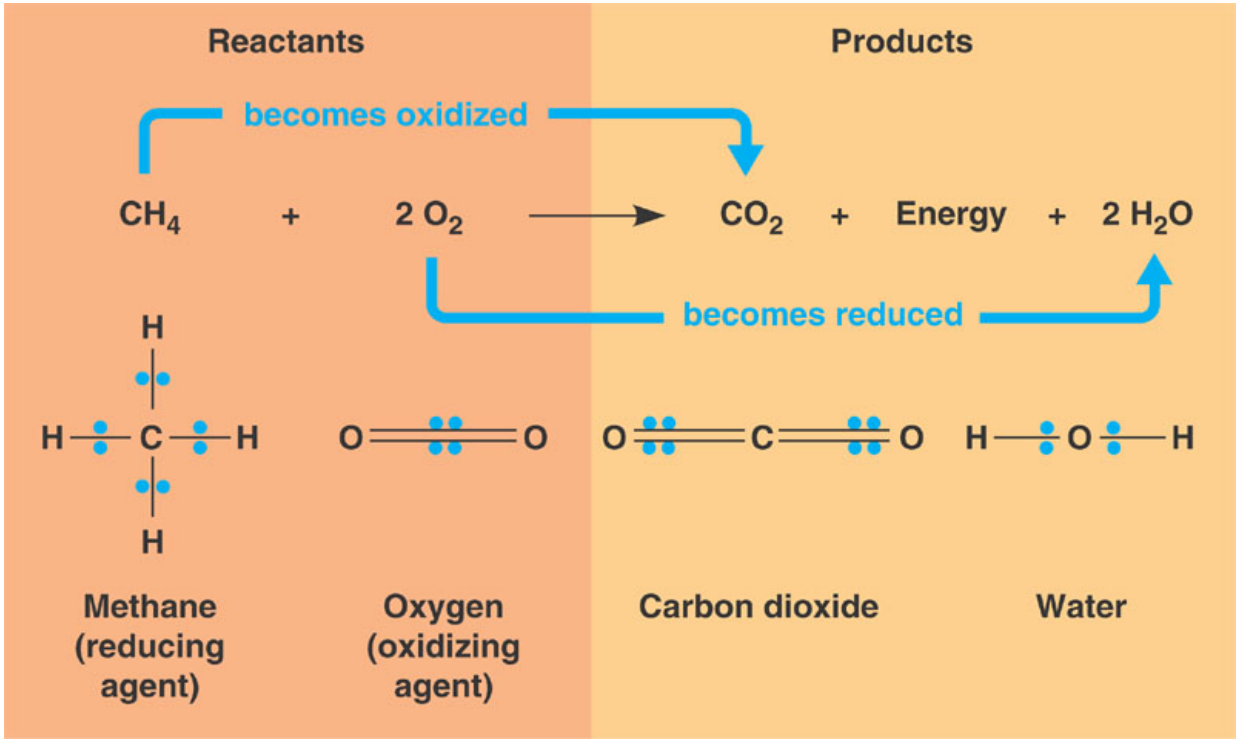
1. Enzyme
2. Substrate w/ phosphate
3. ADP ($2^{nd}$ substrate)
4. Product
5. ATP

# Most ATP is made by *oxidative phosphorylation*




- Food is oxidized
- Electron flow powers ATP synthesis at the inner mitochondrial membrane.

# REDOX



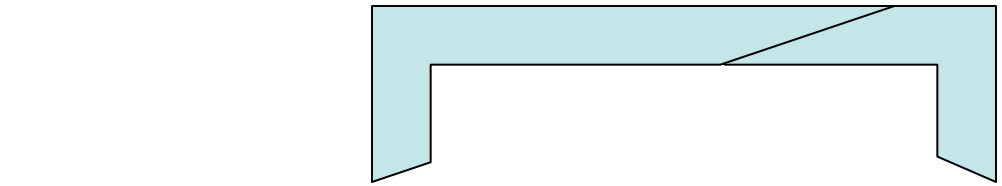

1. Oxidation:
   - loss of electrons (and H)
2. Reduction
   - Gain of electrons (and H)

# Combustion: rapid redox

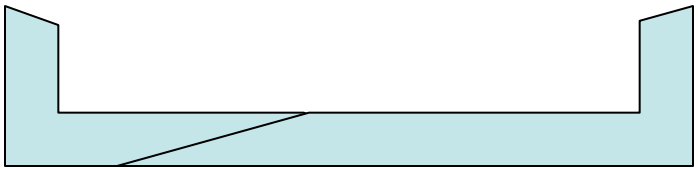
# Respiration

- Slow redox
- Step by step

reduction



$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_20 + ENERGY$$



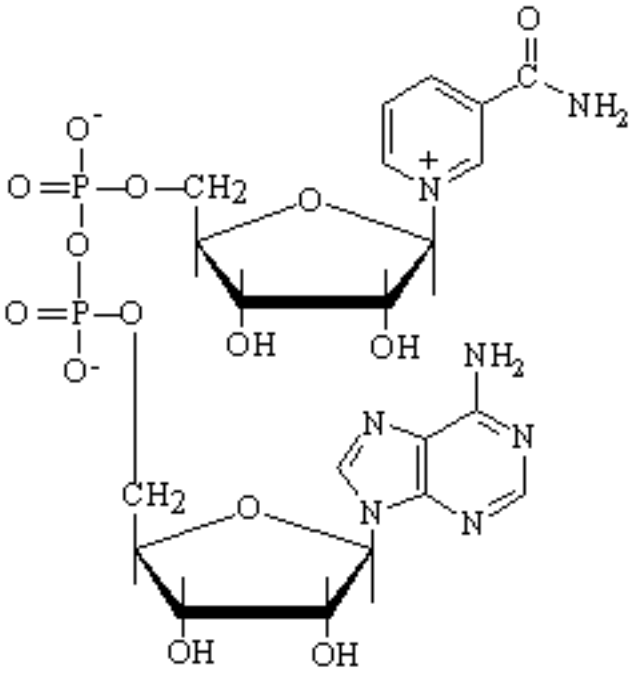
oxidation

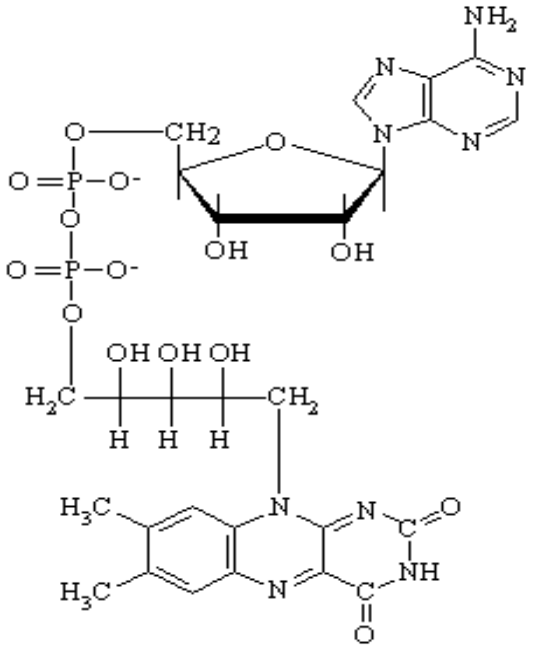
# Step-by-step


(with energy released in small, harvestable steps)

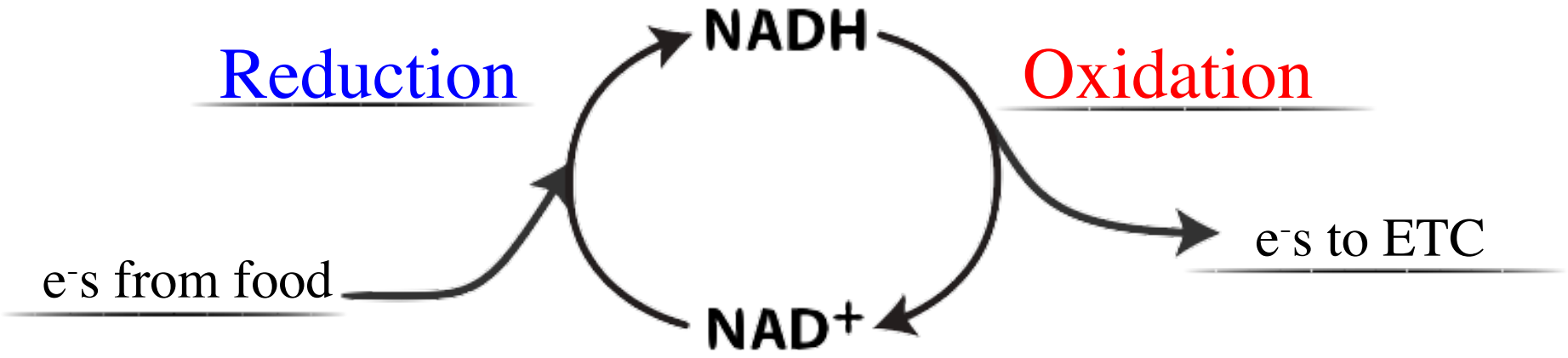
e$^-$s from glucose flow to mobile *electron carriers:*

# $NAD^+$ and FAD

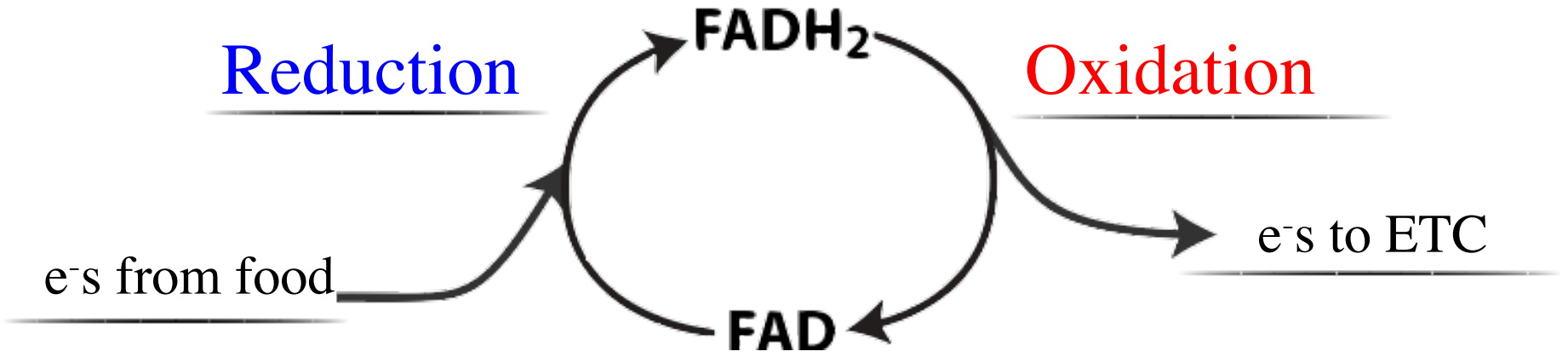




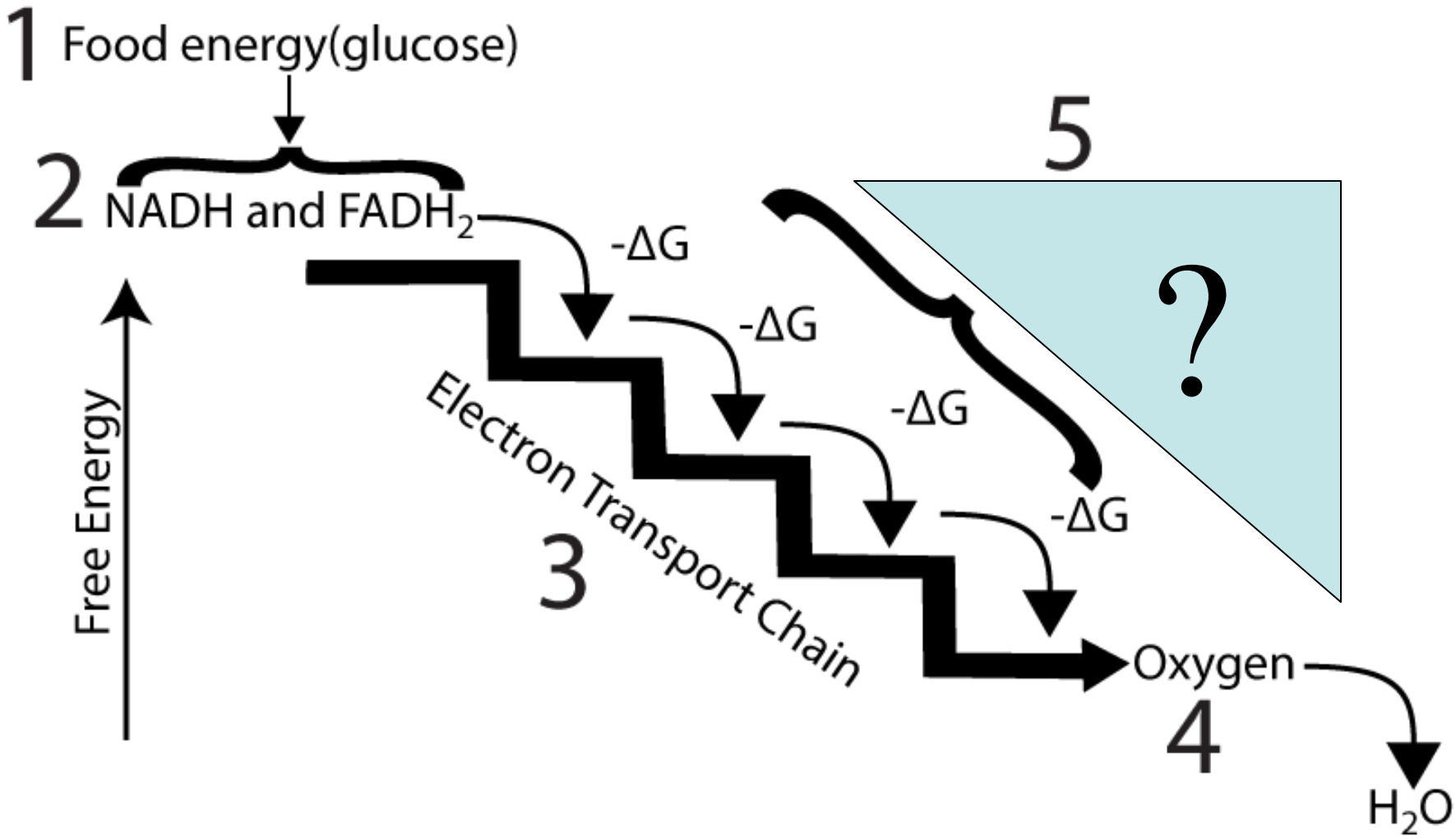
# NADH/NAD+



# $FADH_2/FAD$



# And then NADH and $FADH_2$ are used to make…



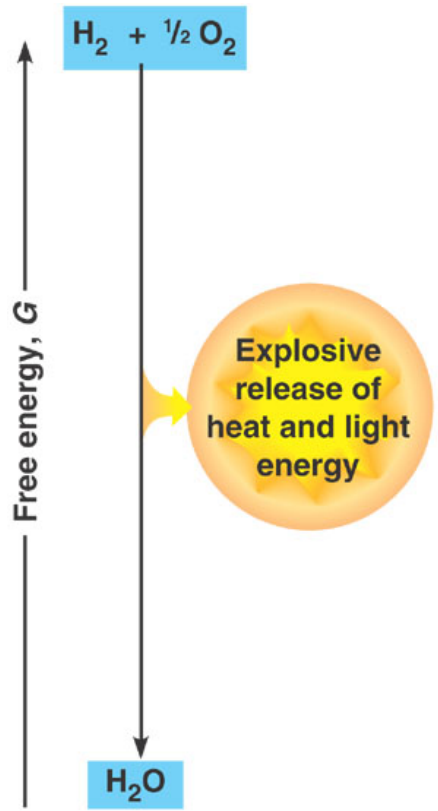
# Discuss and fill in the blanks

- In cellular respiration, food gets _____1_____.
- This enables $NAD^+$ and FAD to be _____2_____ to NADH and ____3_____
- Then, NADH gets ____4_____ to $NAD^+$, providing the energy to make ADP and $P_i$ into ___5___.
- The same thing happens to __6__

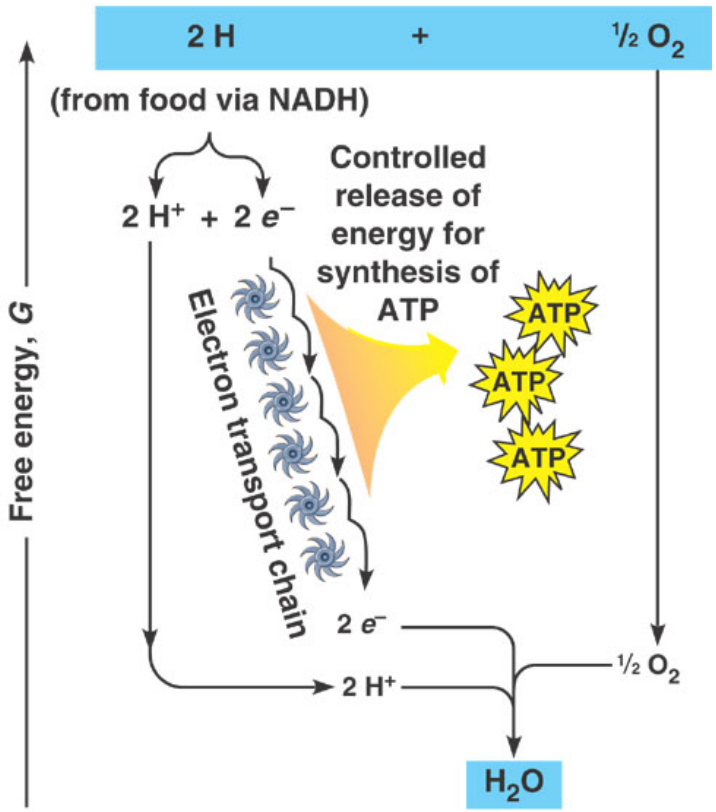
1. oxidized
2. Reduced
3. $FADH_2$
4. Oxidized
5. ATP
6. $FADH_2$

# Which one represents cellular respiration?
# Which one represents combustion?

**1**



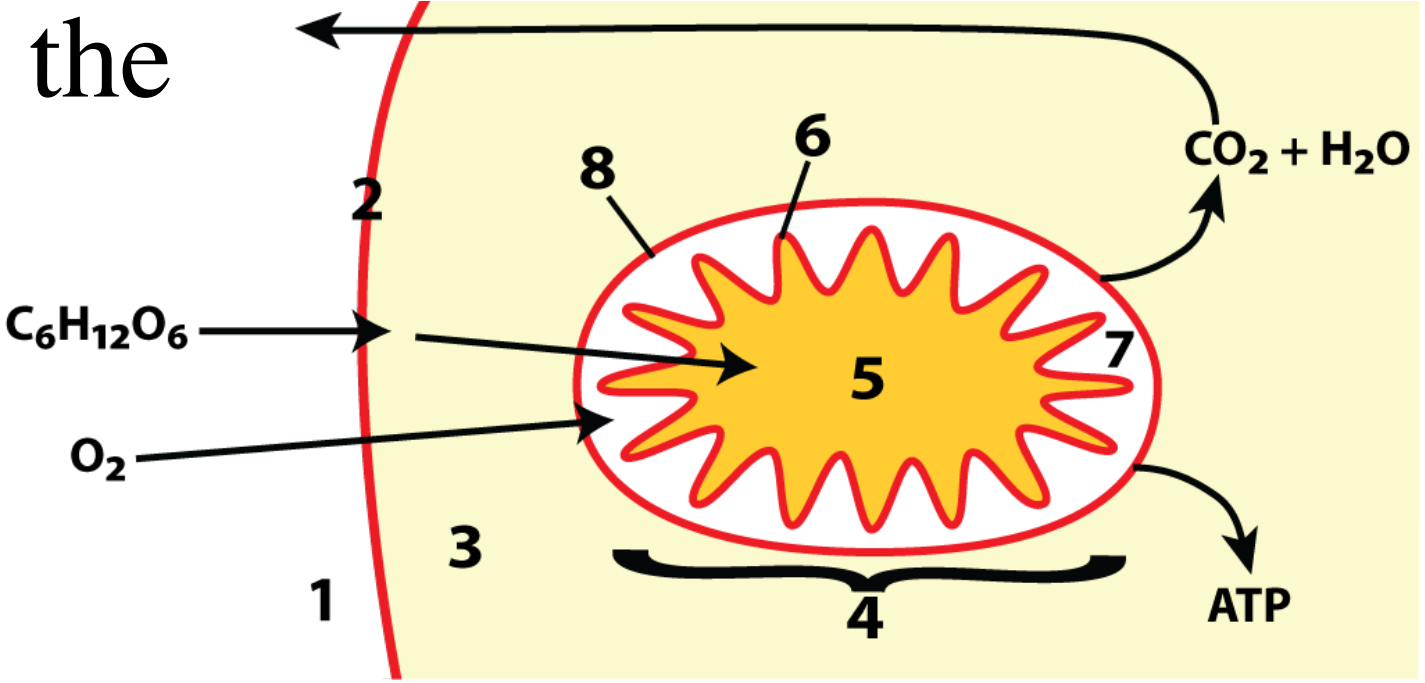

**2**



# Checking Understanding

1. How is cellular respiration like combustion? How is it different?
2. What is the role of NADH and $FADH_2$ in respiration?
3. What happens to glucose in cellular respiration?
4. What's the difference between oxidative and substrate level phosphorylation? Which do you think evolved first? Why?
5. What's the goal of cellular respiration?

# Where in the cell?

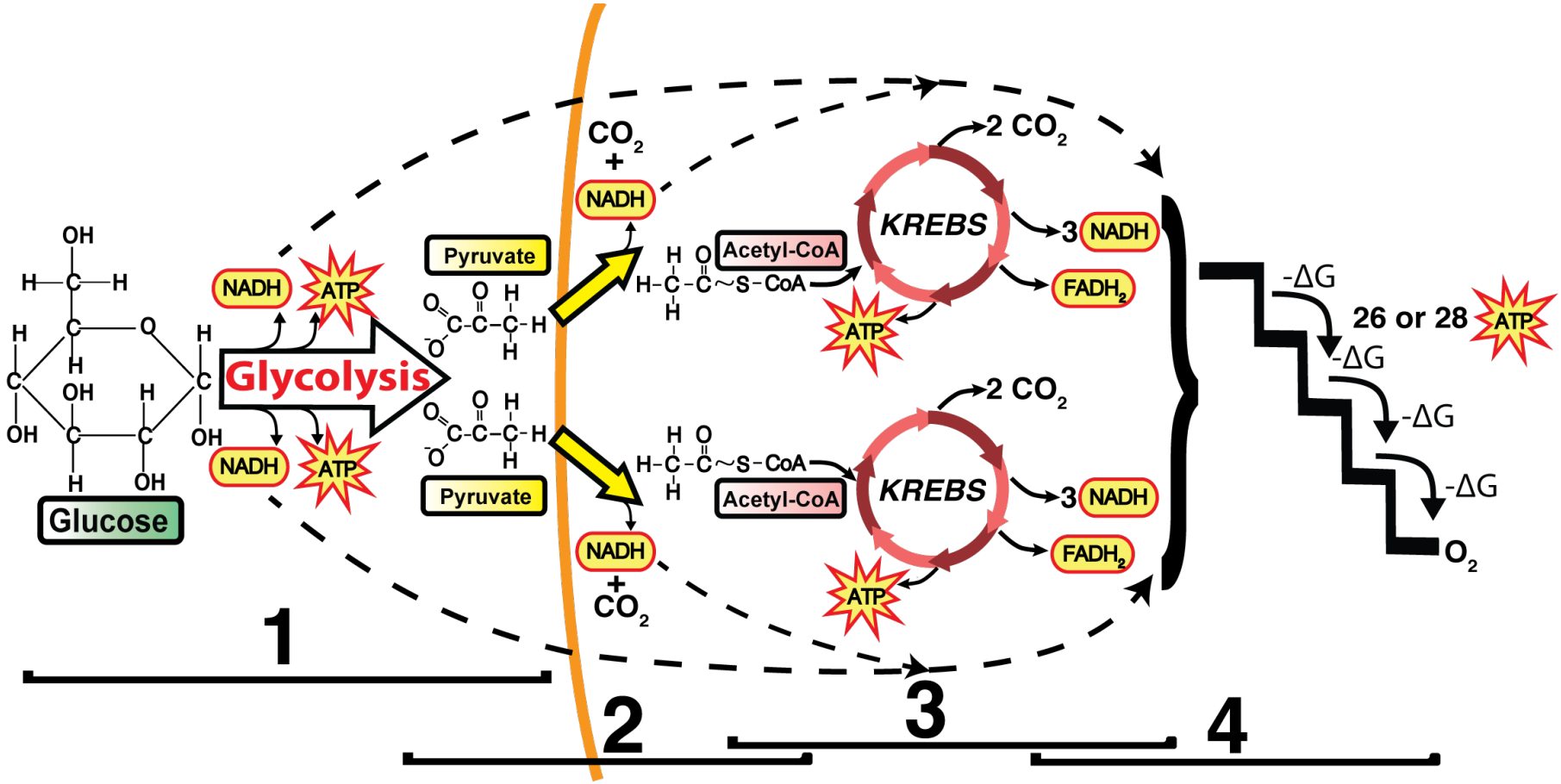



1. Cell exterior
2. Cell Membrane
3. Cytoplasm
4. Mitochondrion
5. Matrix (mitochondrial cytoplasm)
6. Inner membrane (of mit.)
7. Intermembrane space
8. Outer membrane (of mit.)

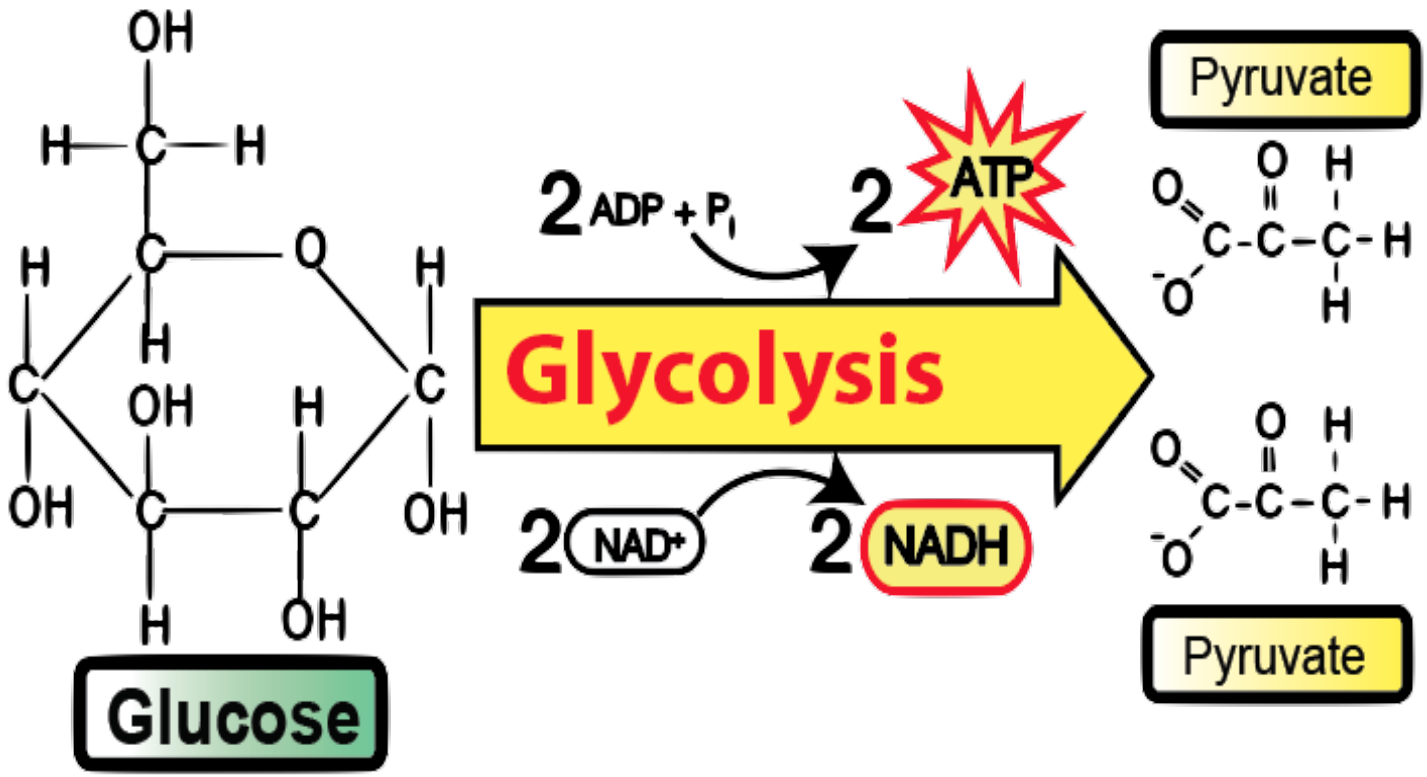
# Part 2

The four phases of respiration

# Respiration has four phases



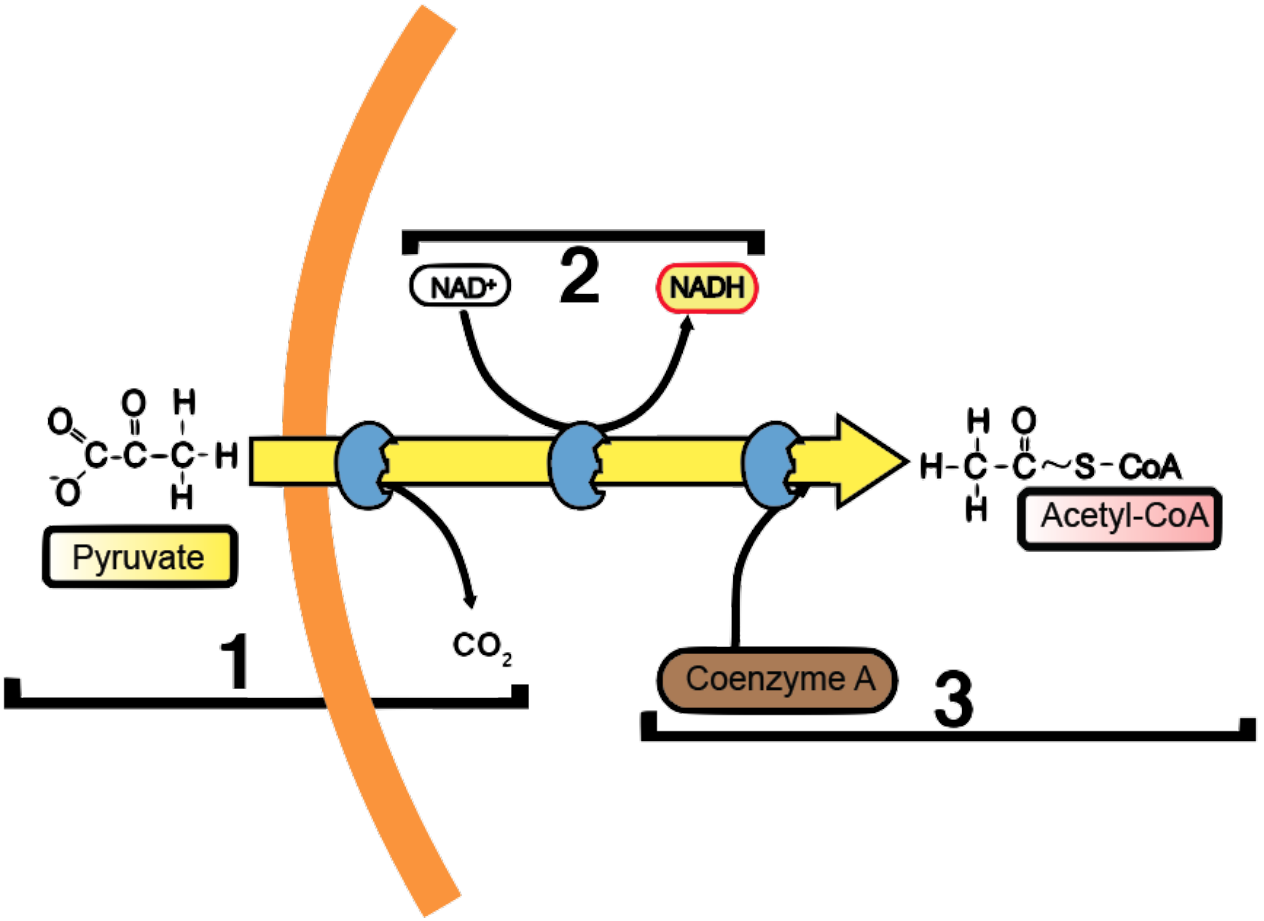
# 1. Glycolysis




- Occurs in cytoplasm

# 2. Link Reaction

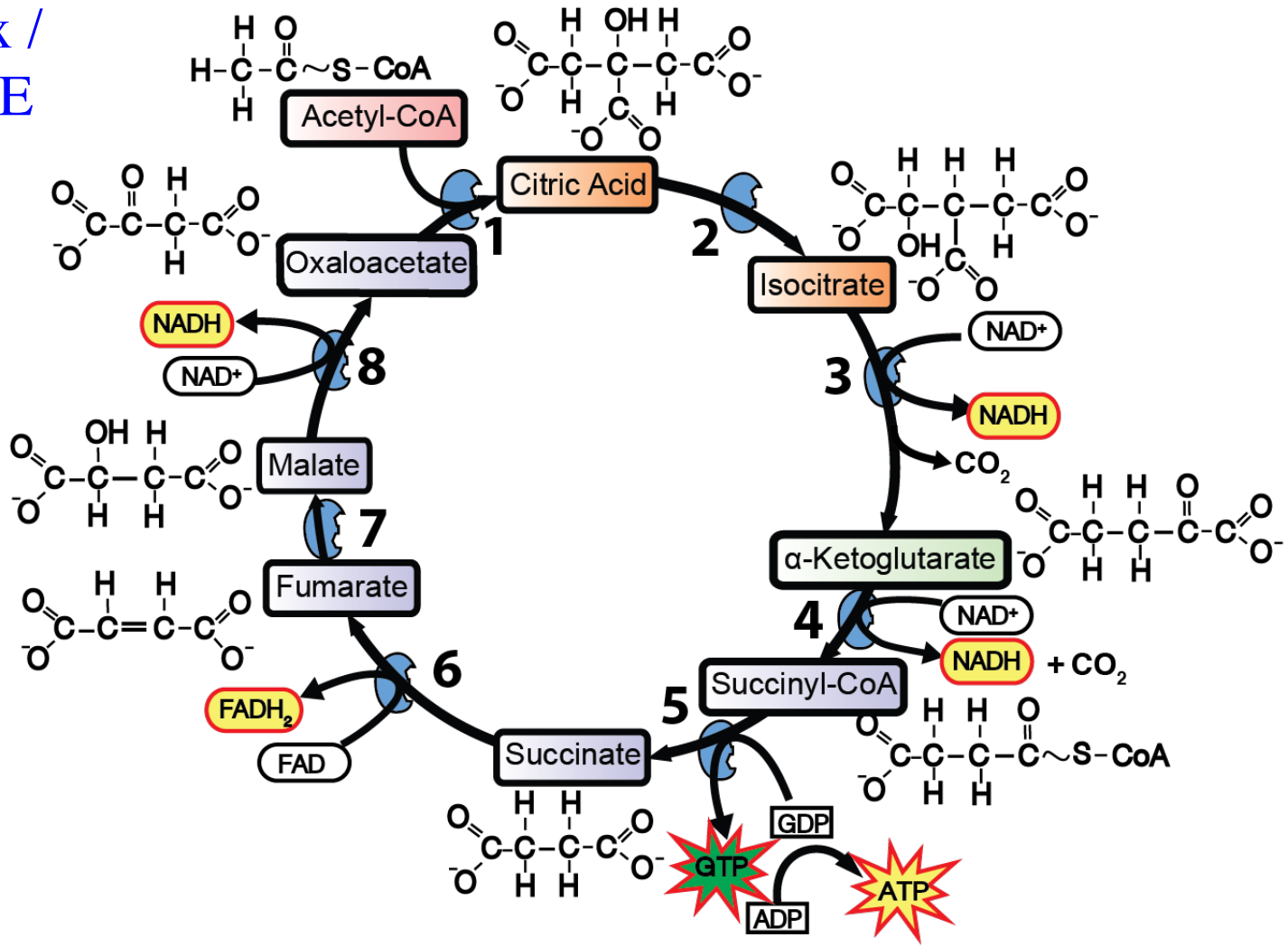
Runs 2x/ glucose




- Pyruvate goes into matrix

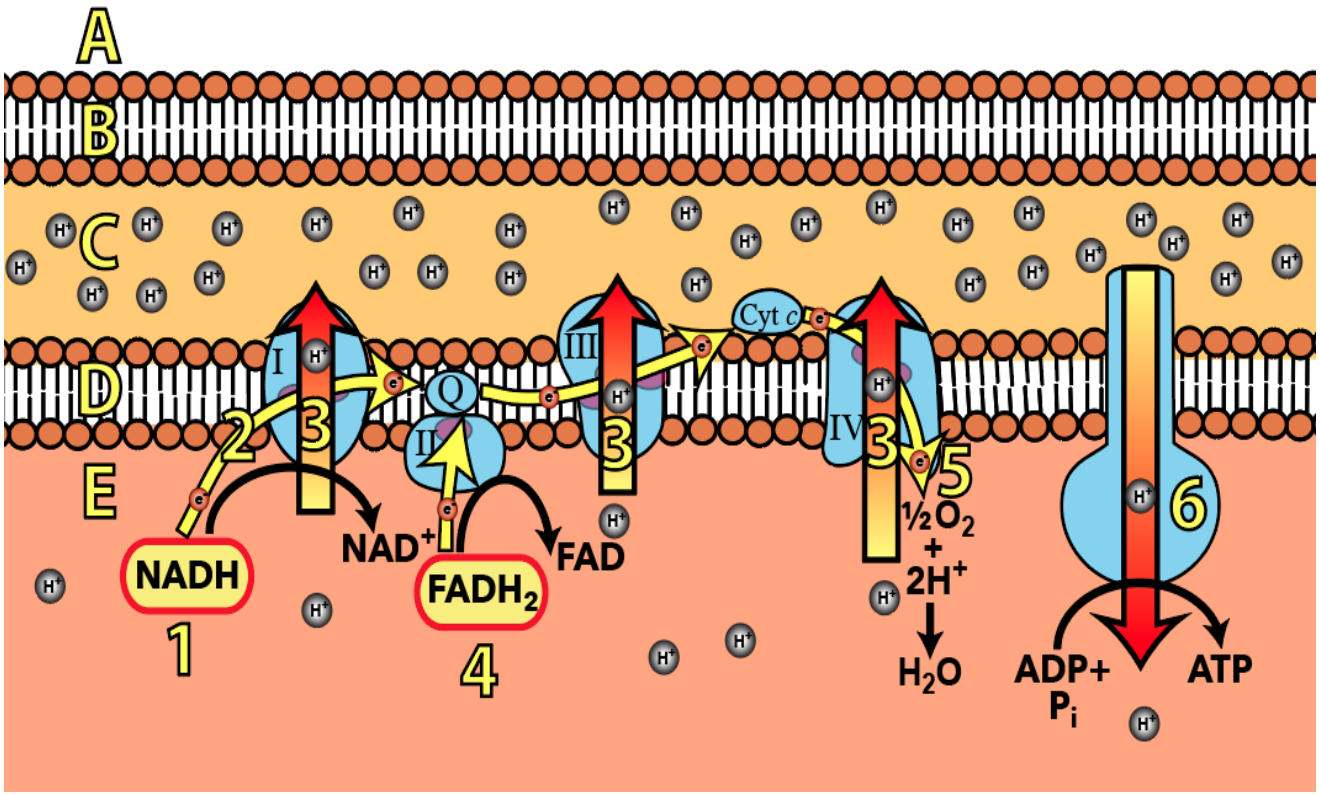
# 3. Krebs Cycle

- RUNS 2 x / GLUCOSE



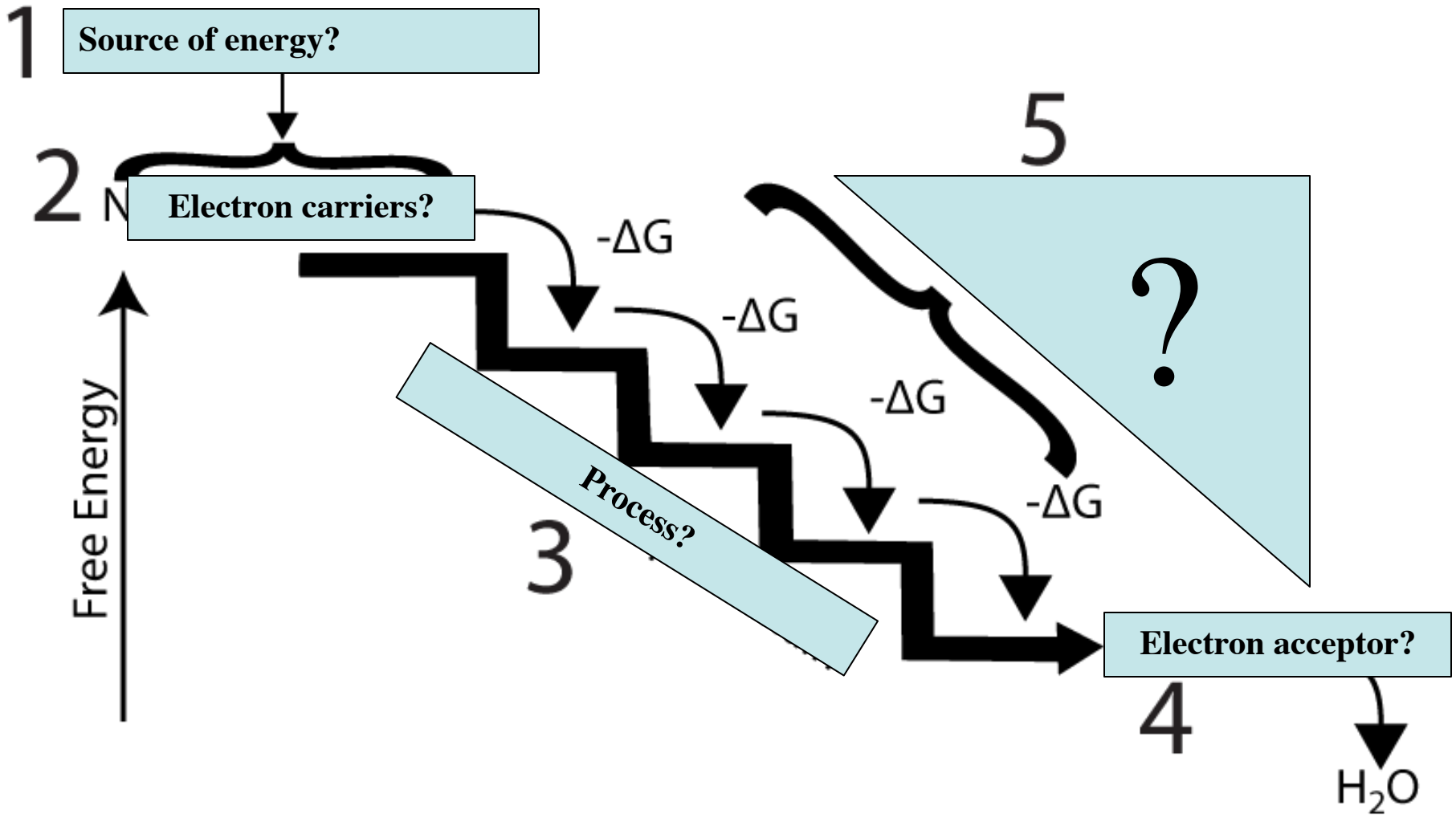

- in matrix

# 4. Mitochondrial ETC

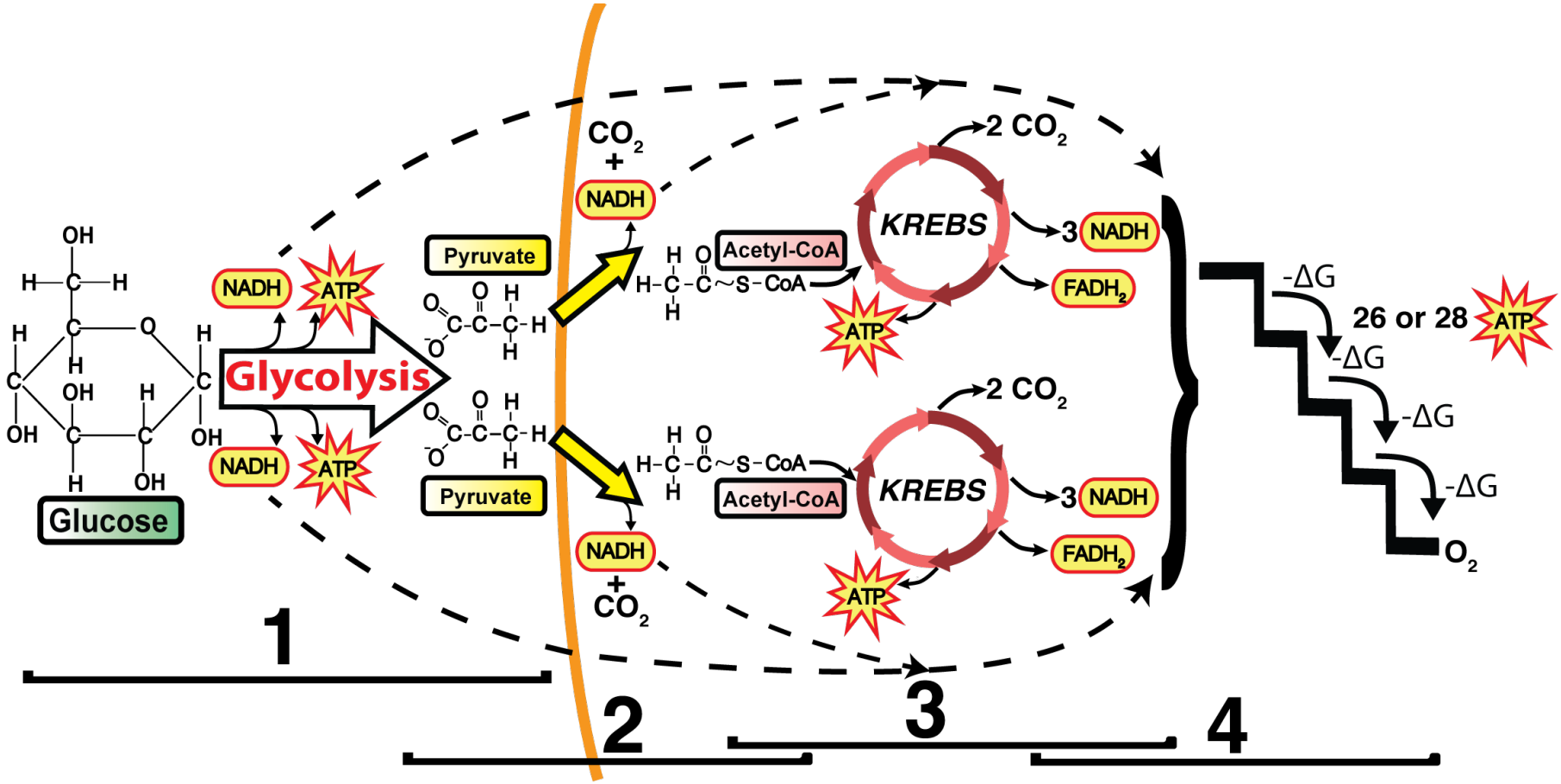



- Involves inner membrane and intermembrane space.
- Oxidative phosphorylation

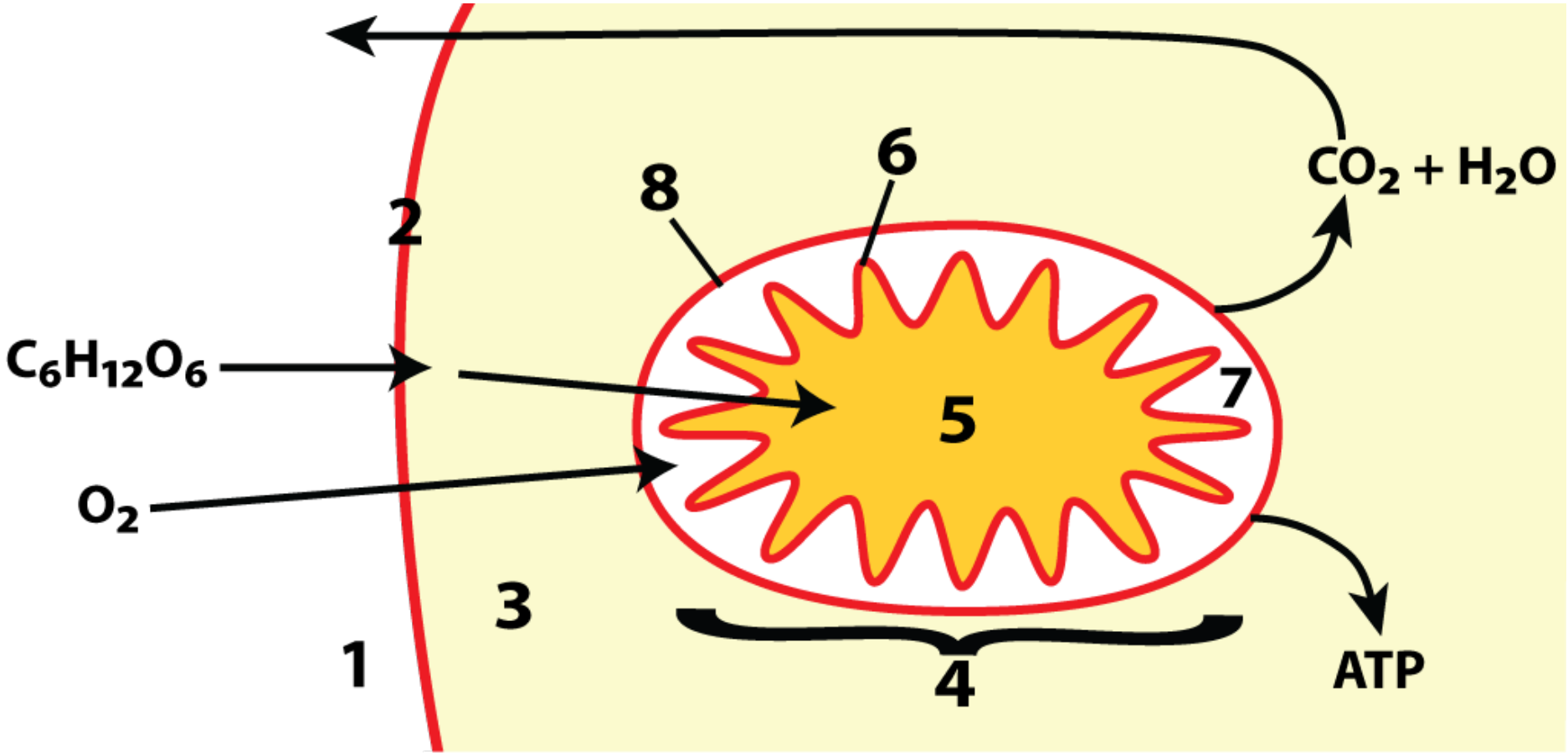
# Talk through this …



# Talk through the diagram…



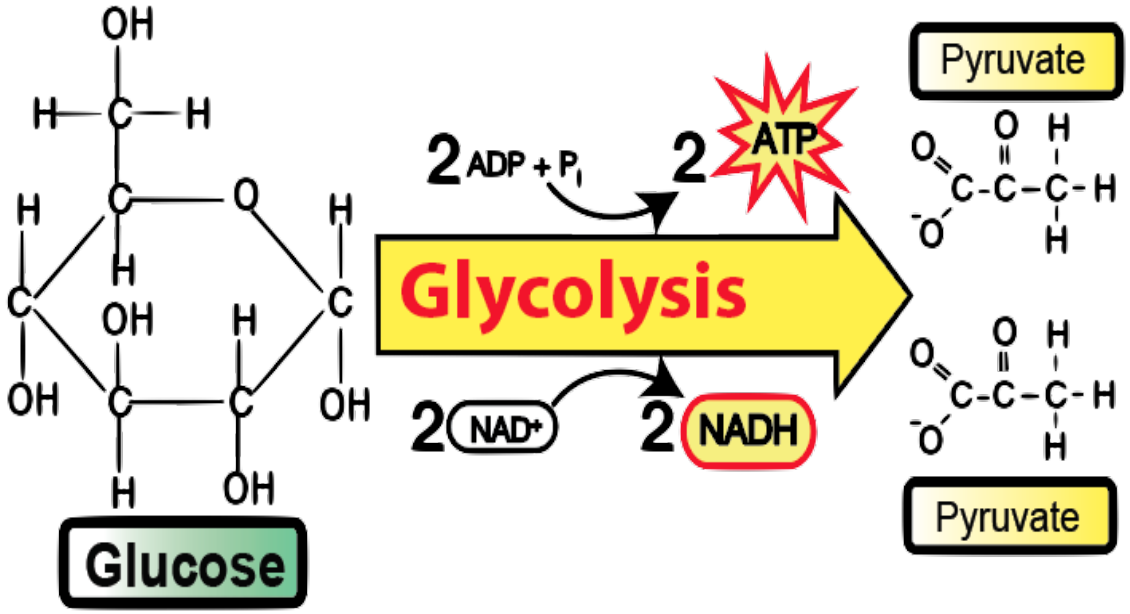
# Checking Understanding



# Part 3

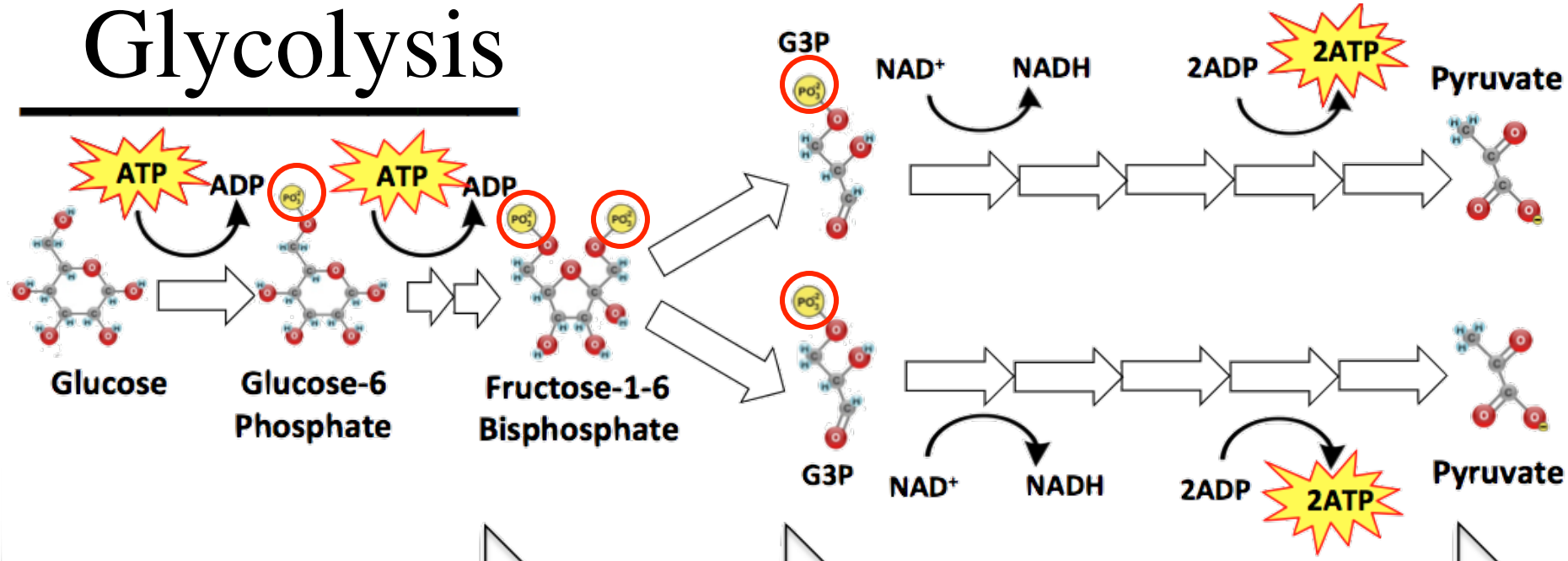
Glycolysis

# Very Simplified Glycolysis

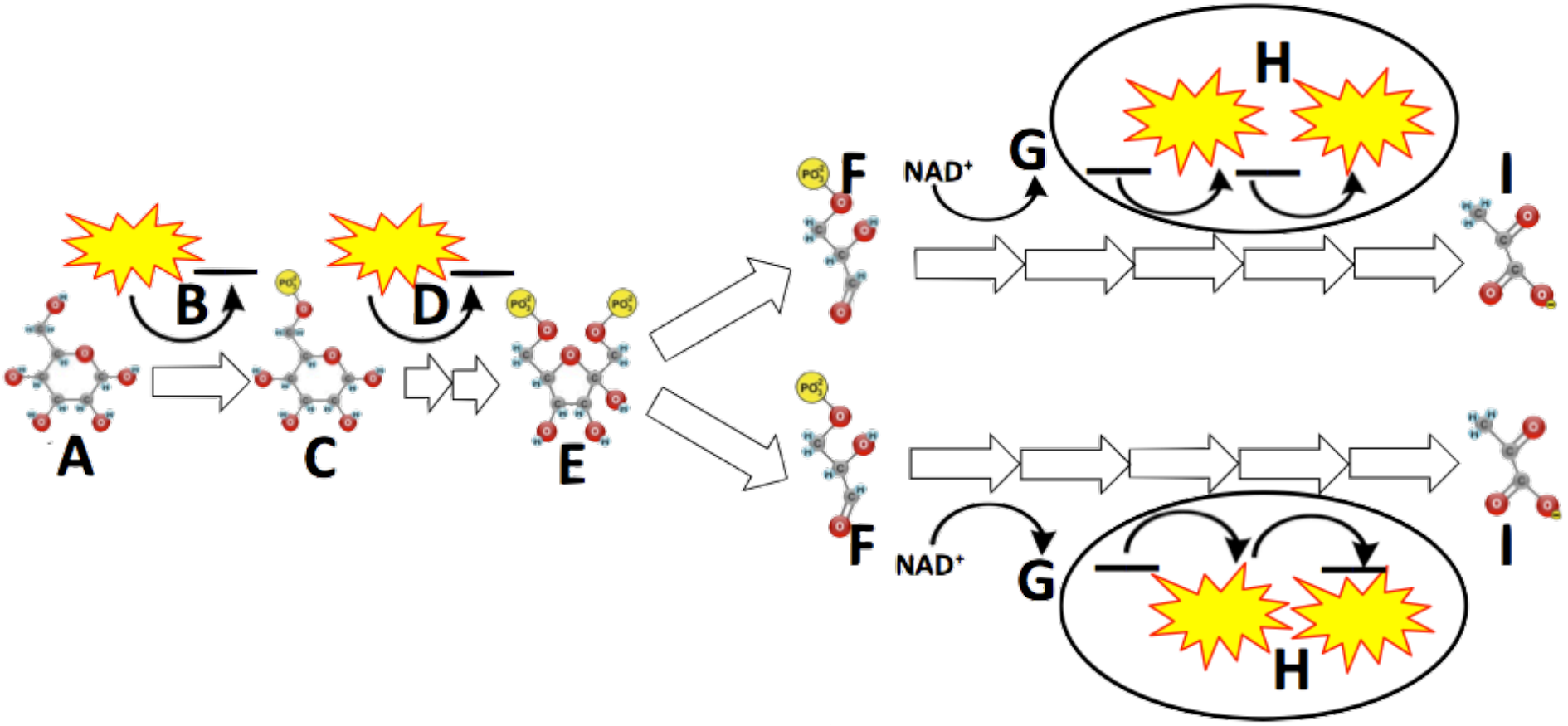



a. Splits glucose
b. Makes two NADH
c. Makes 2 ATP
d. End product: pyruvic acid

# Glycolysis

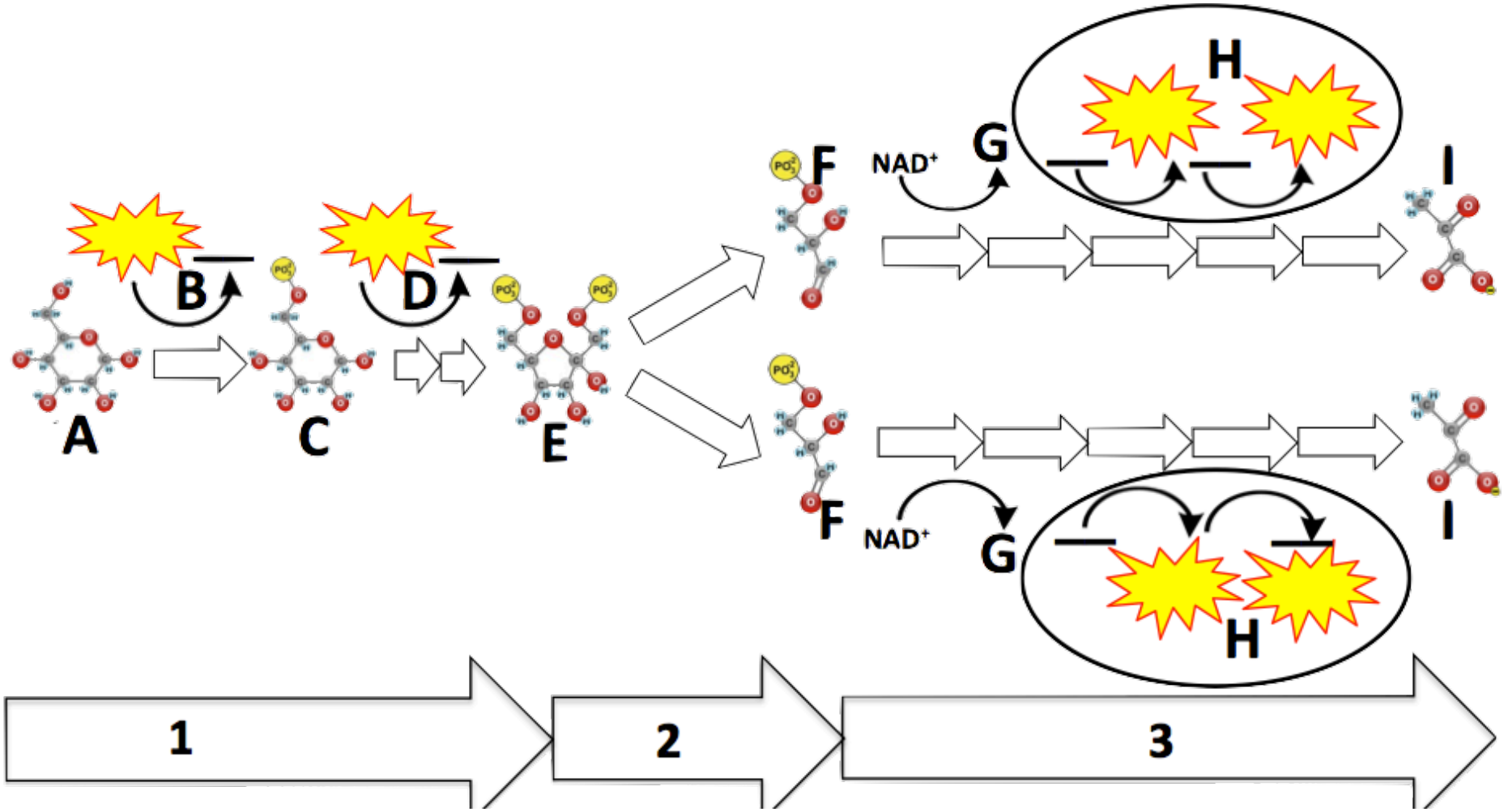


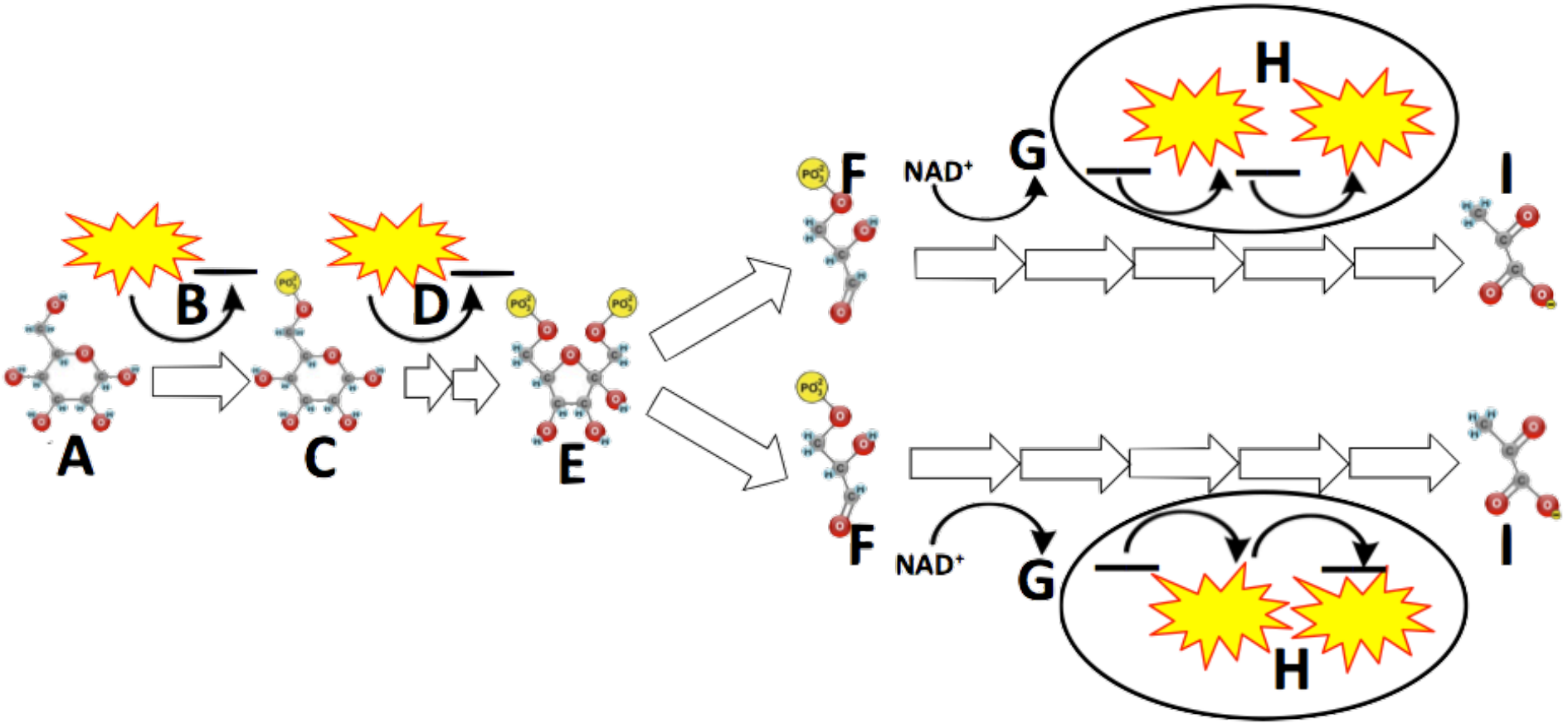

**Investment** **Cleavage** **Harvest**




1. A➔E: investment (cost = 2 ATPs)
2. E-F: Cleavage ➔ G3P (glyceraldehyde -3 Phosphate)
3. F➔I: Harvest
   GROSS= 4 ATPs by SLP, 2NADHs
4. NET GAIN: 2 ATPs, 2NADHs

# You explain it…






1. A➔E: investment (cost = 2 ATPs)
2. E-F: Cleavage ➔ G3P (glyceraldehyde -3 Phosphate)
3. F➔I: Harvest
   GROSS= 4 ATPs by SLP, 2NADHs
4. NET GAIN: 2 ATPs, 2NADHs

Date: 10/31. Number: 3-7. Title: **Glycolysis**

**OBJECTIVE: Explain the link reaction and Krebs cycle.**

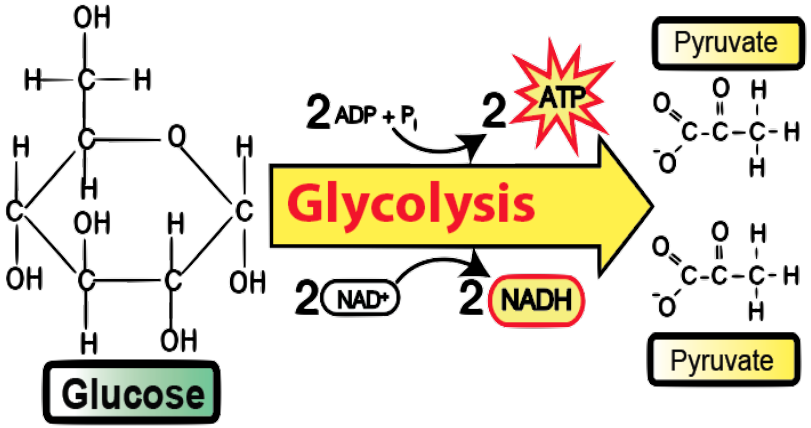
**HOMEWORK: (see agenda) Finish chapter 7 flashcards.**

**Write a brief description of what happens during glycolysis**

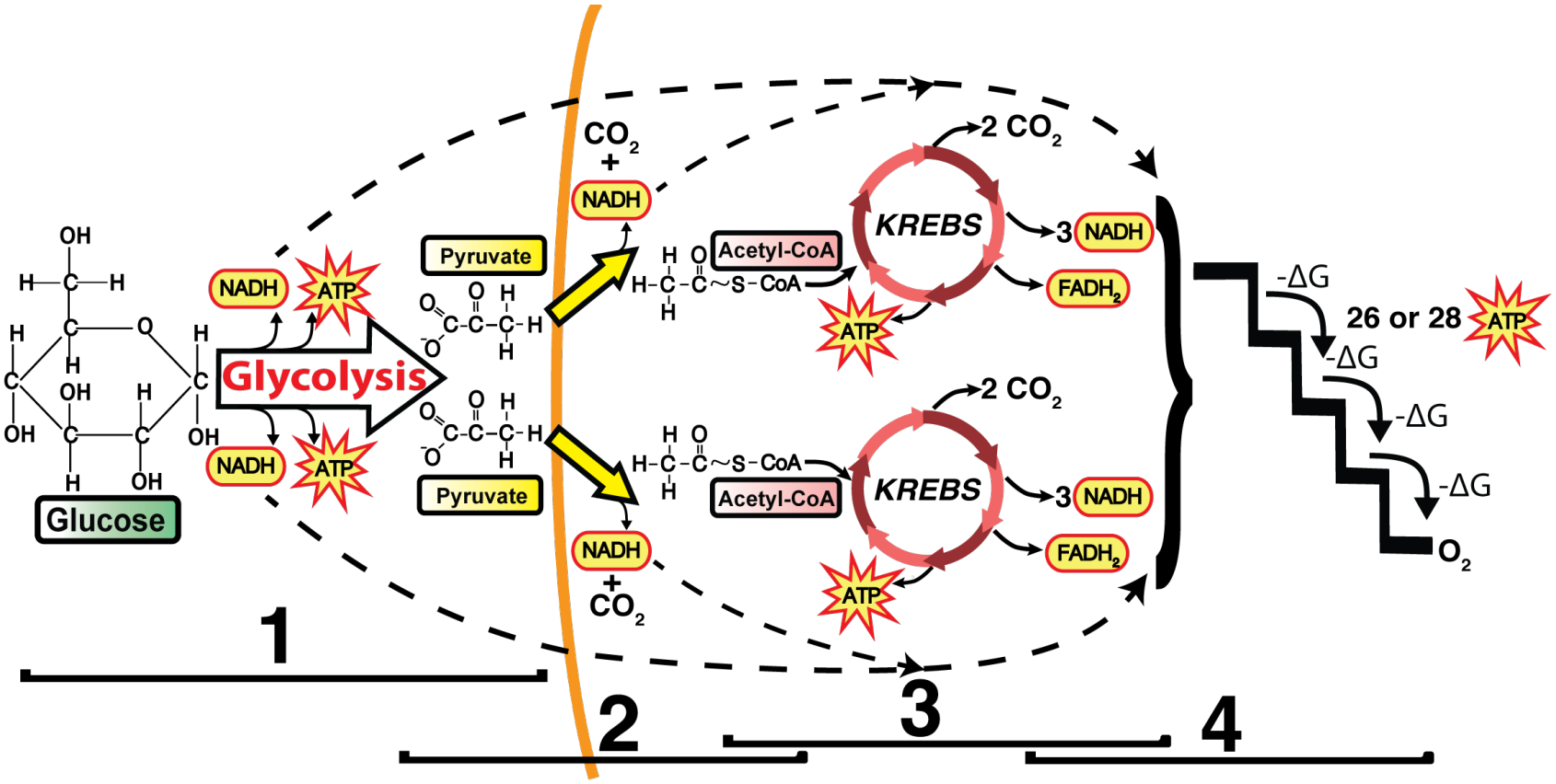
**During glycolysis.....**

**POSSIBLE ANSWER:**

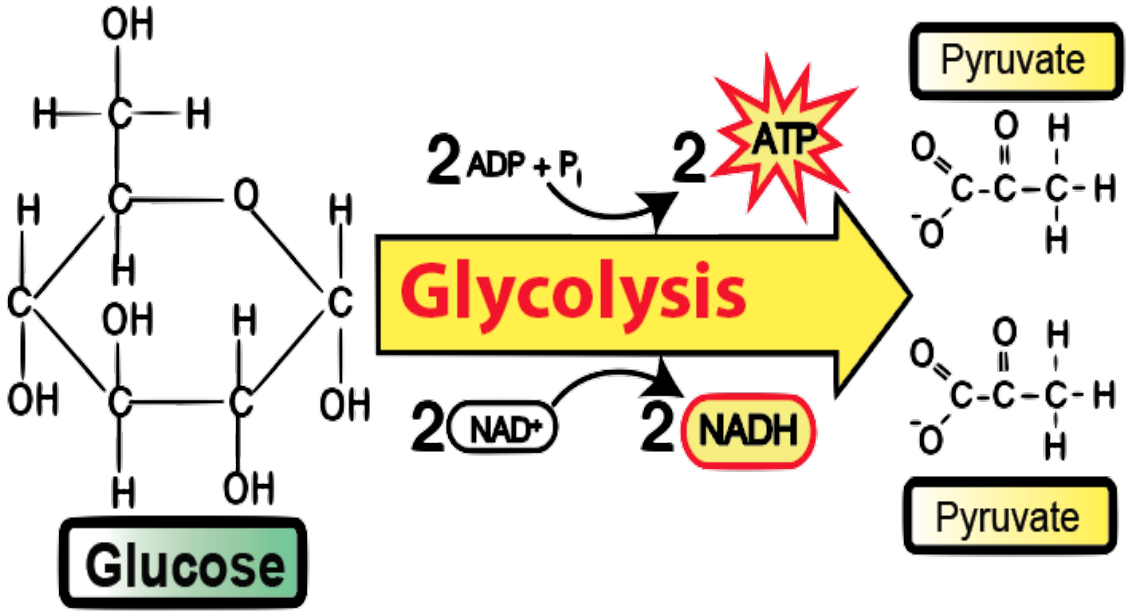
**During glycolysis, glucose gets broken into two molecules of pyruvic acid. As this happens, glucose's chemical energy is used to create two ATPs by a substrate level phosphorylation, and to reduce two $NAD^+$s to NADH.**



# Take out your lecture notes from yesterday



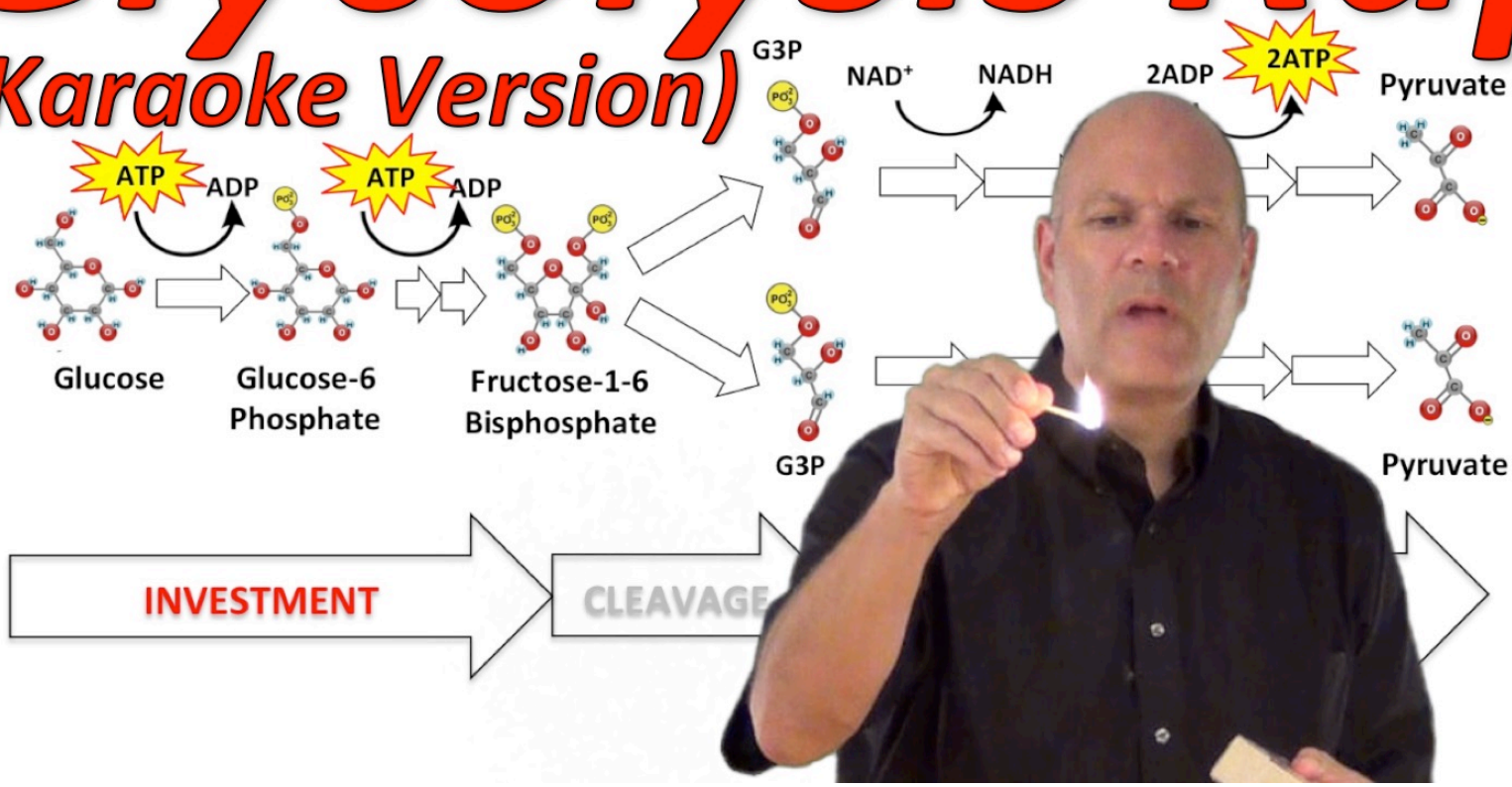
# Simplified Glycolysis




a. Splits glucose
b. Makes two NADH
c. Makes 2 ATP
d. End product: pyruvic acid

# Glycolysis Rap

## (Karaoke Version)

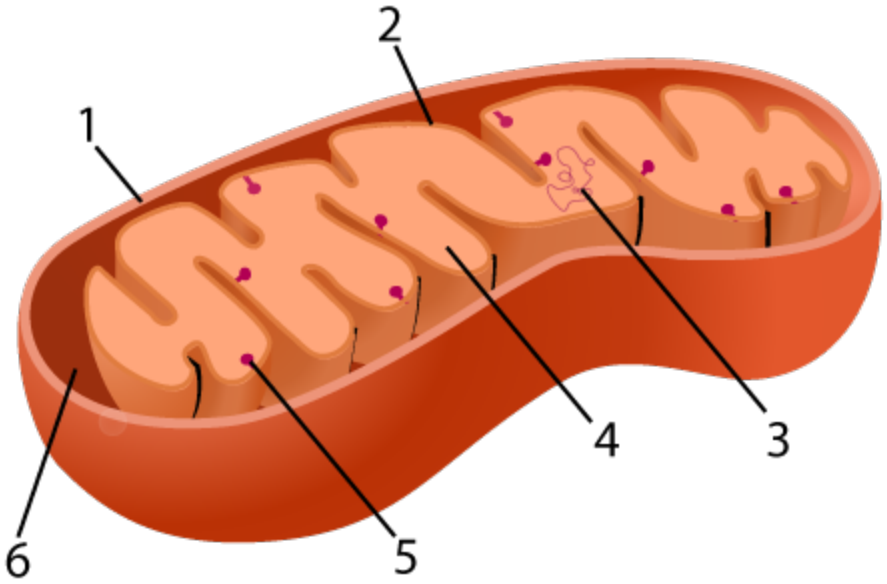



[Cellular Respiration: A Musical Review]

# Part 4

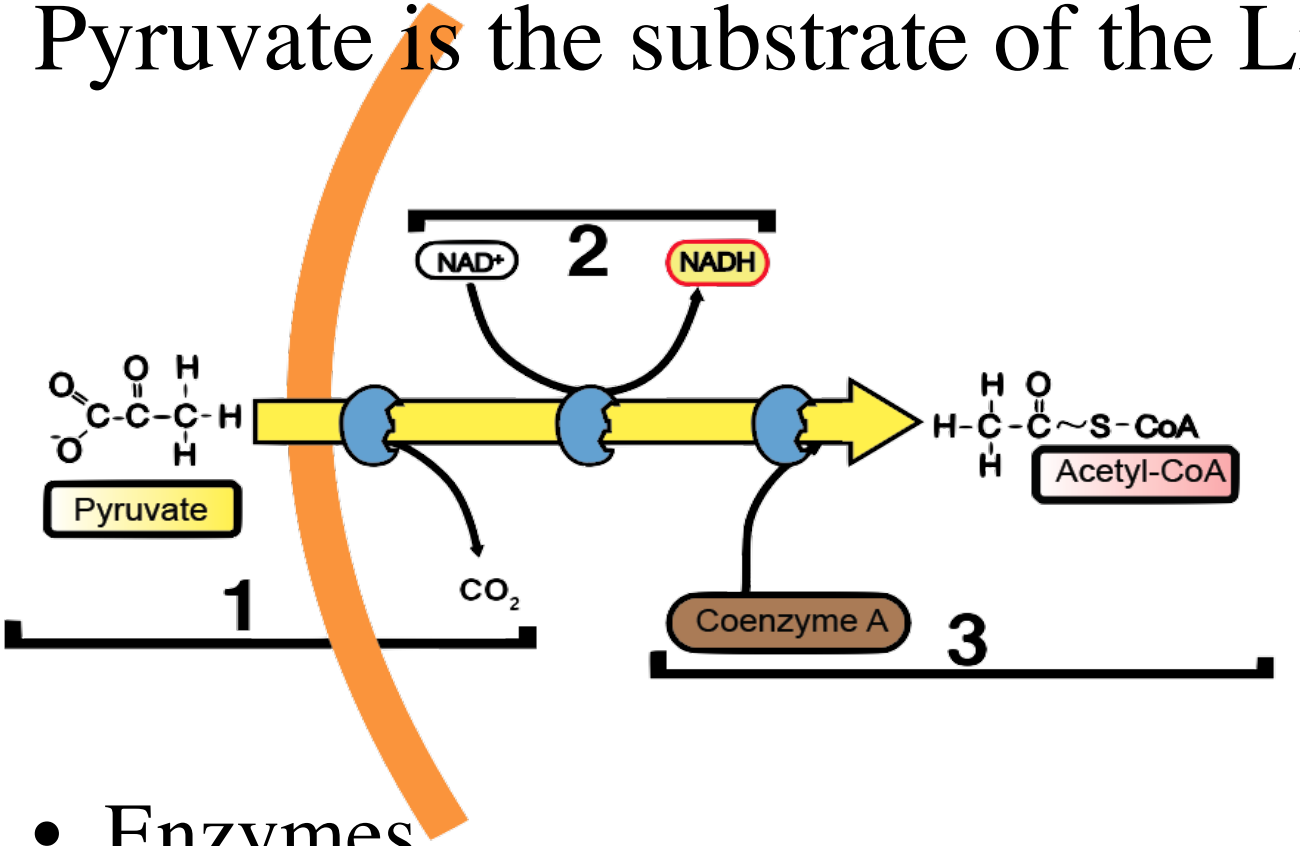
Link reaction and Krebs cycle

# After glycolysis (if there's $O_2$), everything happens in the mitochondria



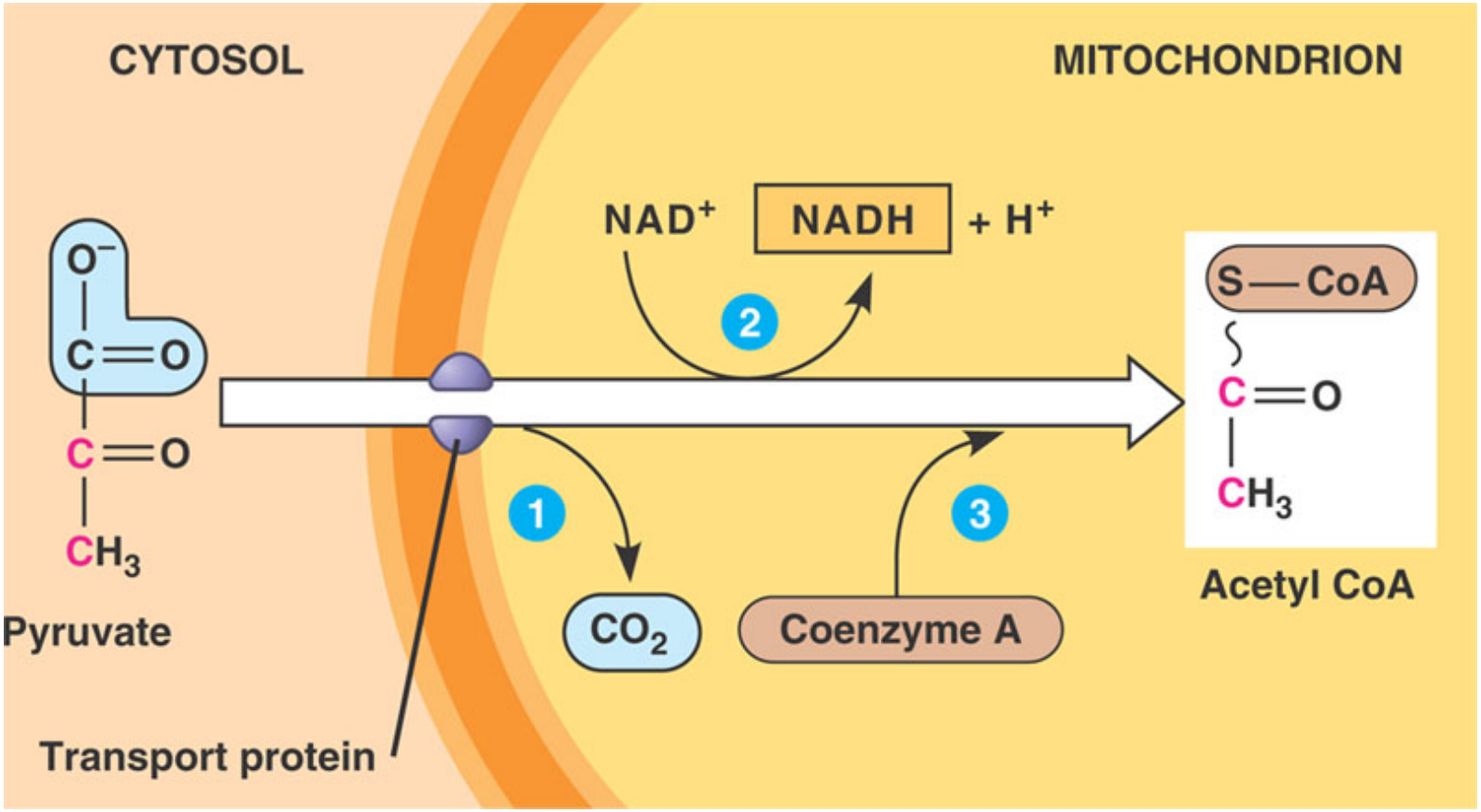

1. outer membrane
2. Inner membrane, studded with enzymes. (Why is it so internally folded?)
3. DNA
4. Matrix
5. ATP synthase
6. Inter-membrane space

# Pyruvate is the substrate of the Link Reaction



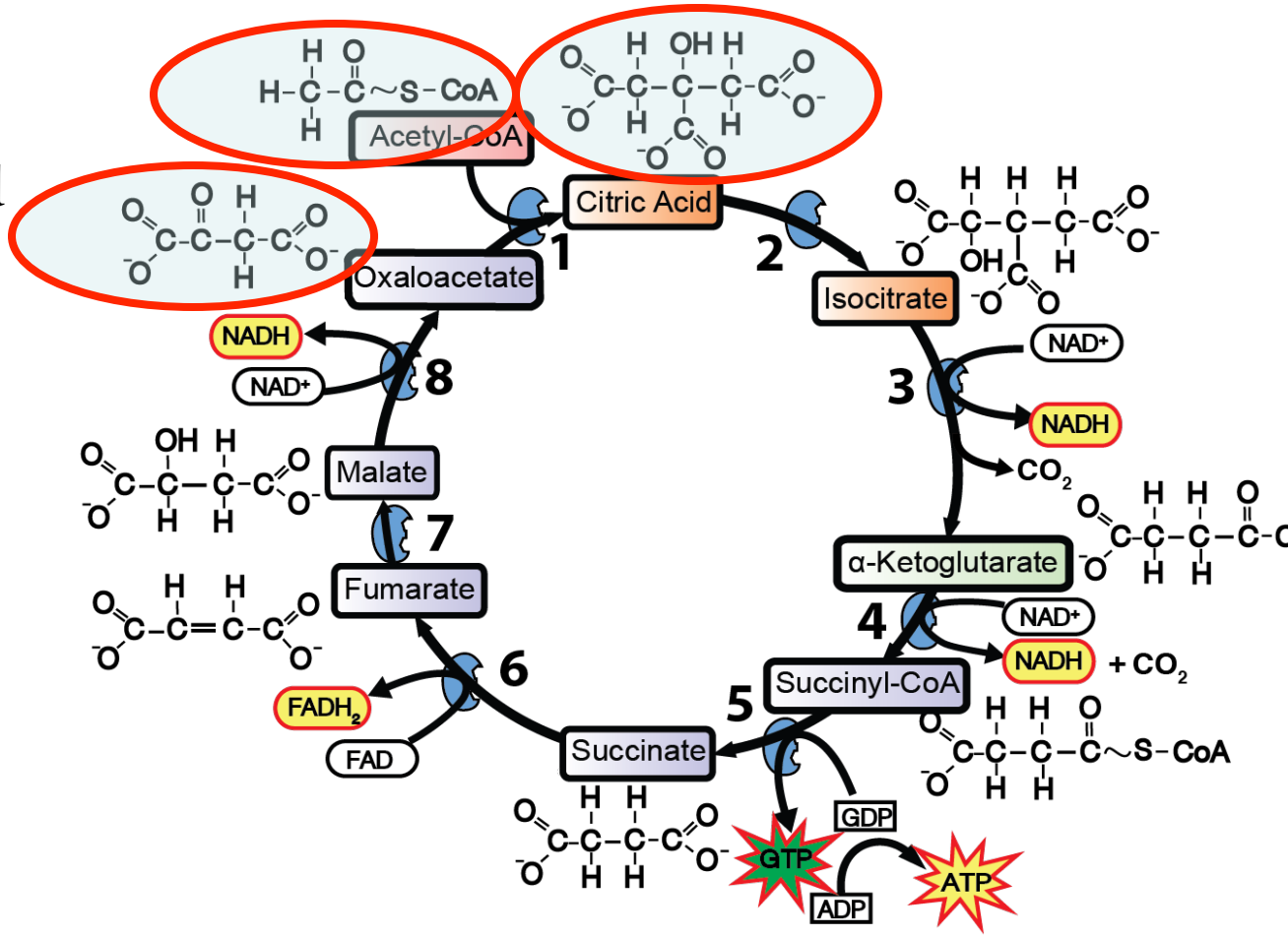

- Enzymes
  - remove a $CO_2$
  - Oxidize pyruvate/ Reduce $NAD^+$ to NADH
  - Attach two carbons to Coenzyme A -> Acetyl-CoA

# From Pyruvate to Acetyl CoA: Checking Understanding



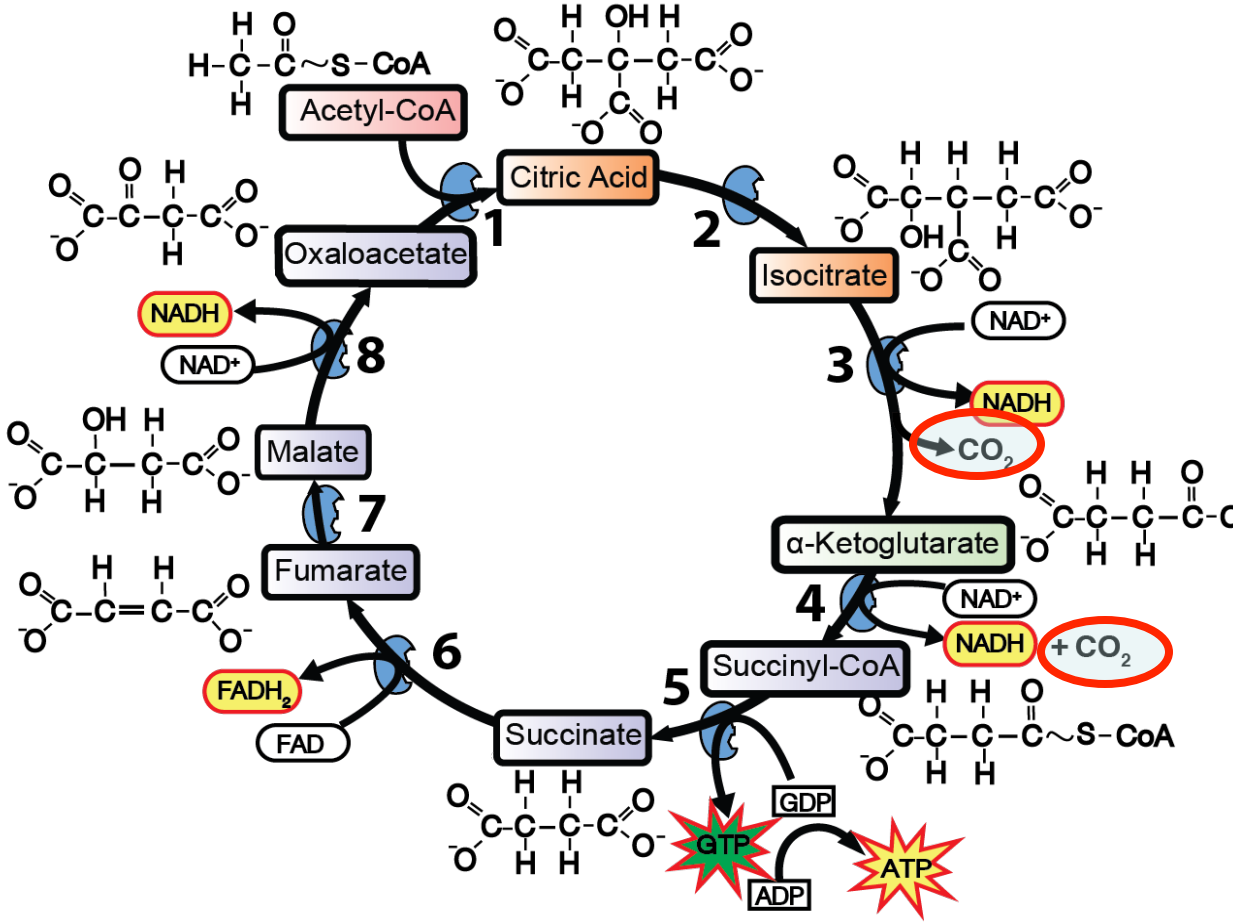
# Krebs (Citric Acid) Cycle: Key Points (1)

- 2 carbons go in as acetyl Co-A
- These get attached to *oxaloacetate* (4Cs)
- Creates *citrate* (6Cs)



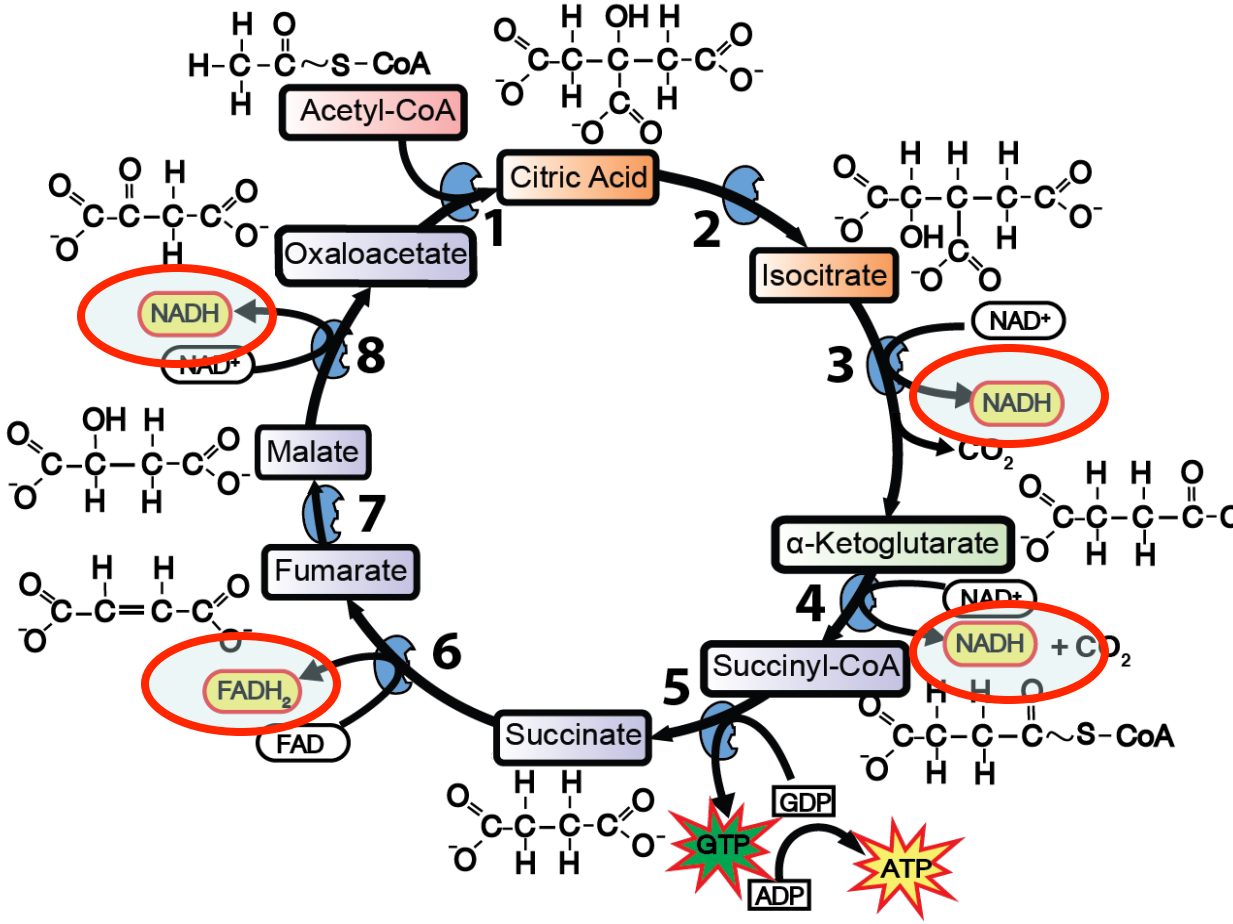
# Krebs (Citric Acid) Cycle: Key Points (2)

- 2 $CO_2$s are released



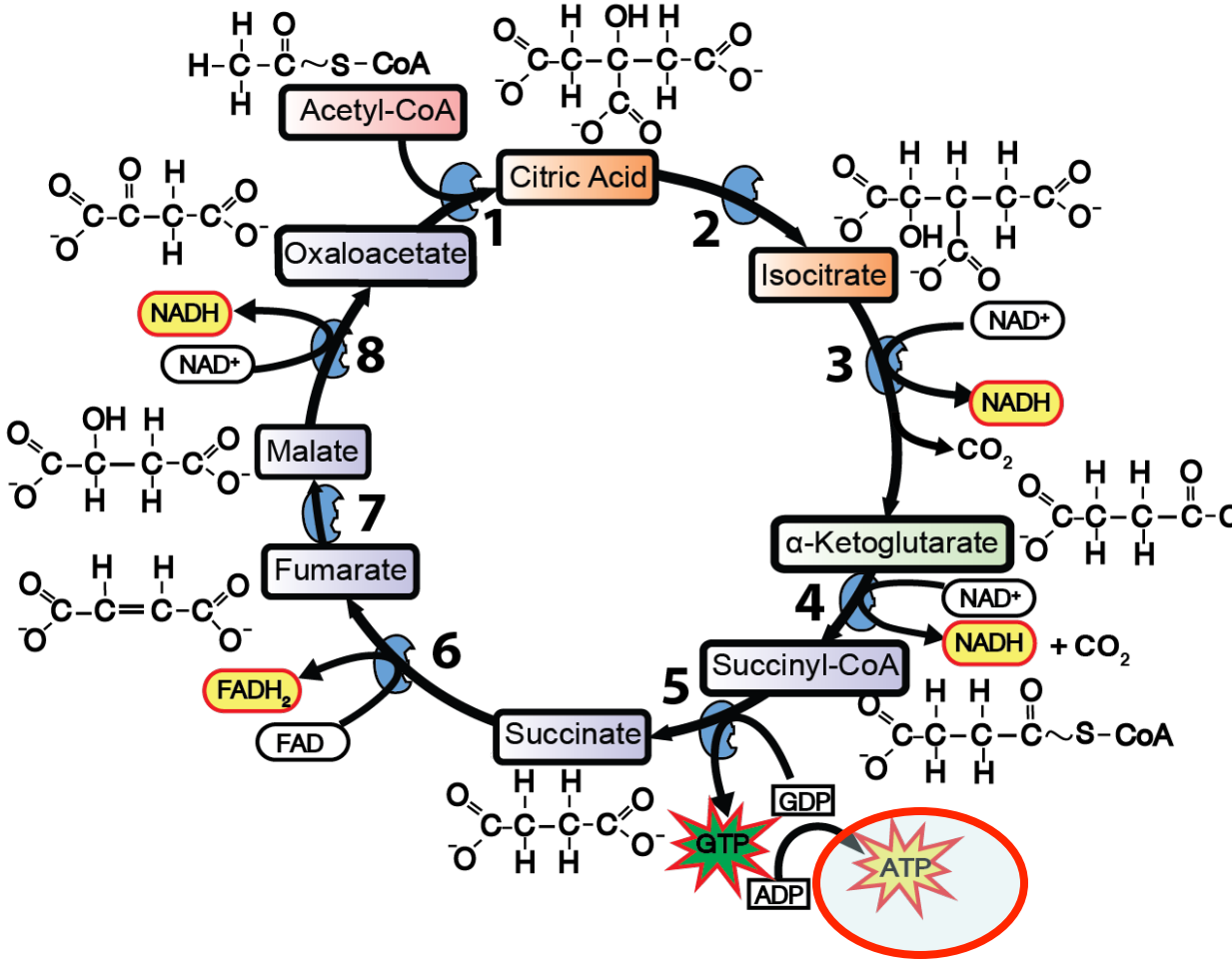
# Krebs (Citric Acid) Cycle: Key Points (3)

- 3 NADHs and 1 $FADH_2$ are generated (REDOX)



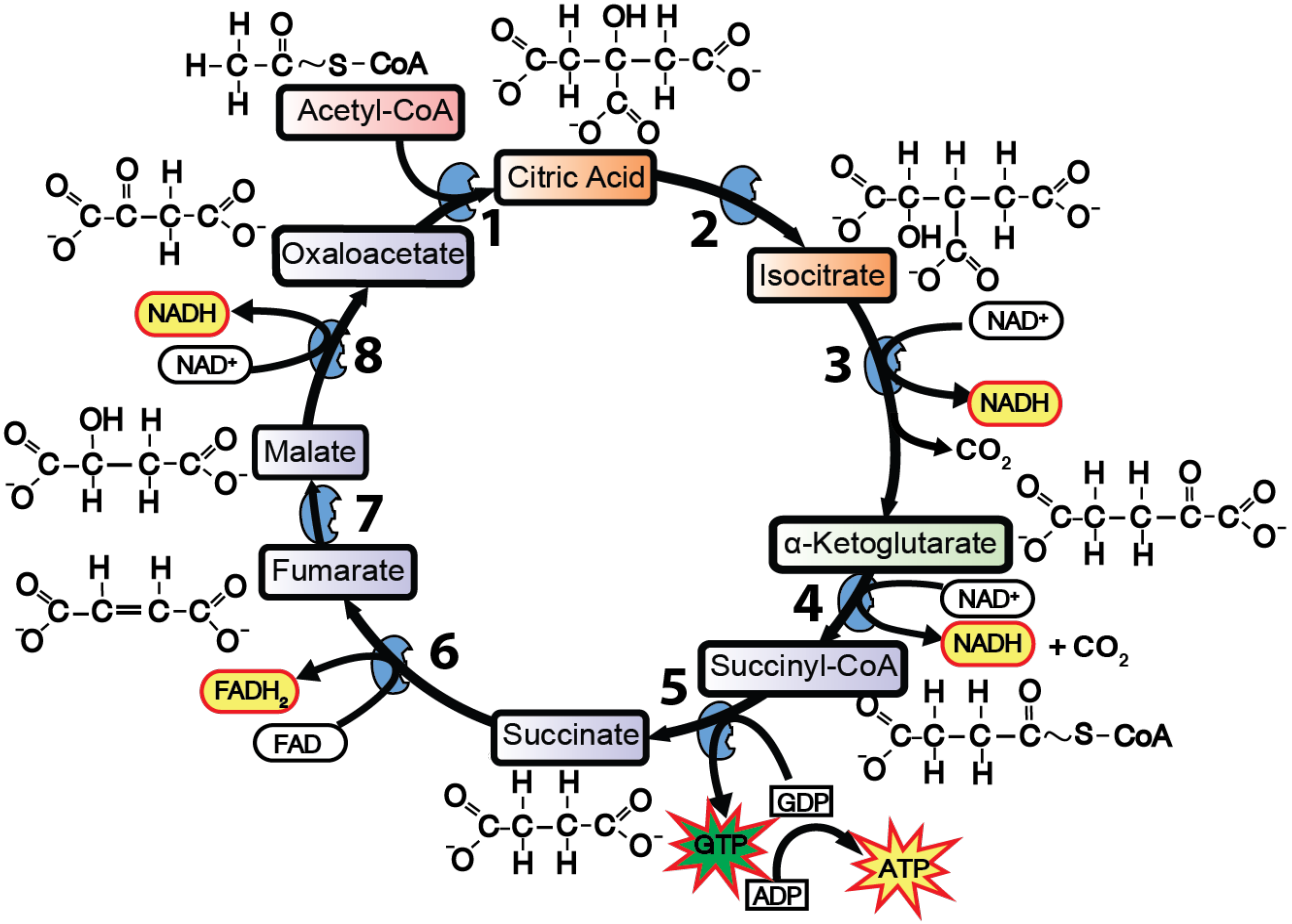
# Krebs (Citric Acid) Cycle: Key Points (4)

- 1 ATP is generated by a substrate level phosphorylation



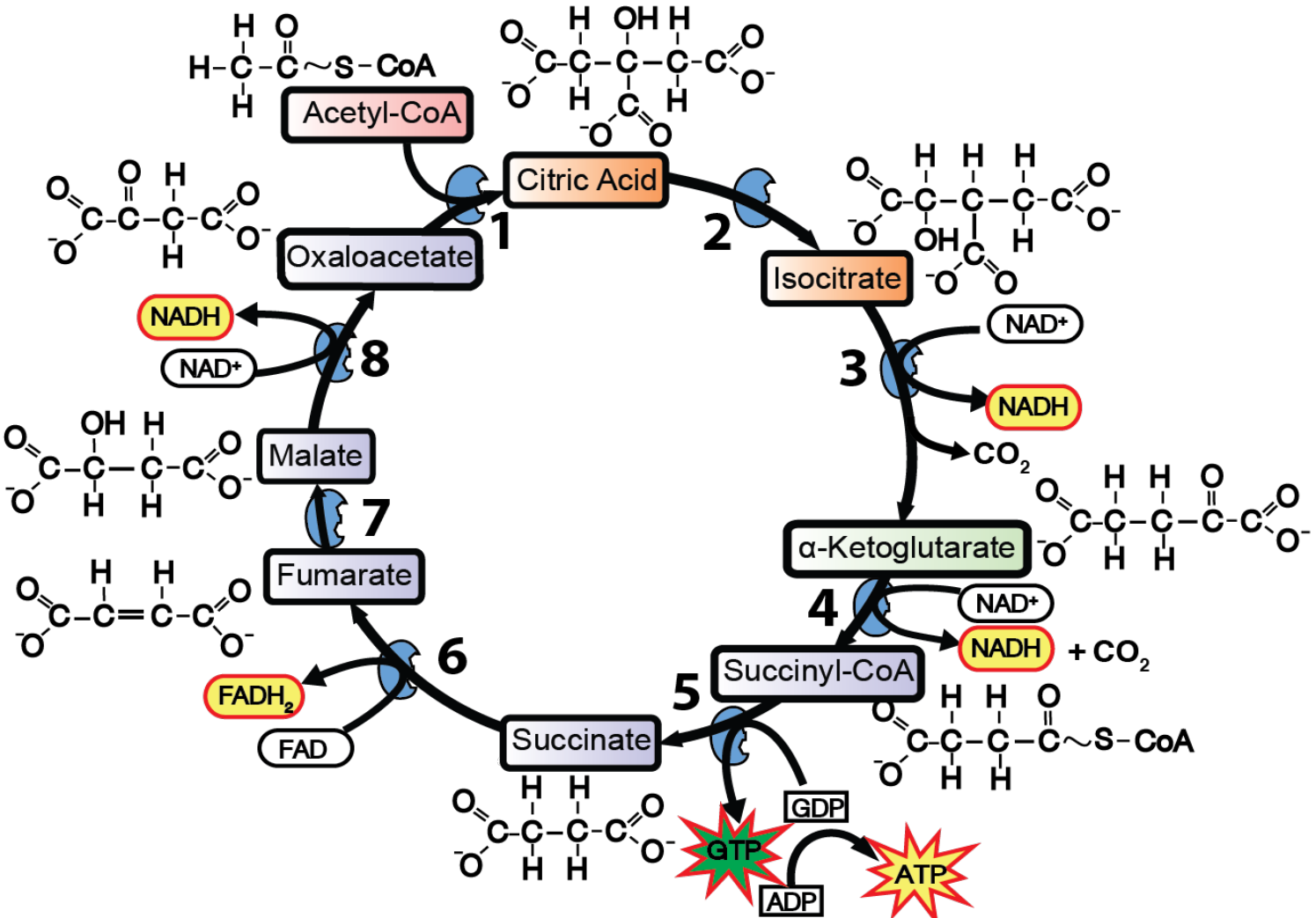
# Krebs (Citric Acid) Cycle: checking understanding

1. Where is there a substrate level phosphorylation?
2. Where are there redox reactions?
3. Where are enzymes releasing $CO_2$?
4. Where is reduced carbon entering the cycle?

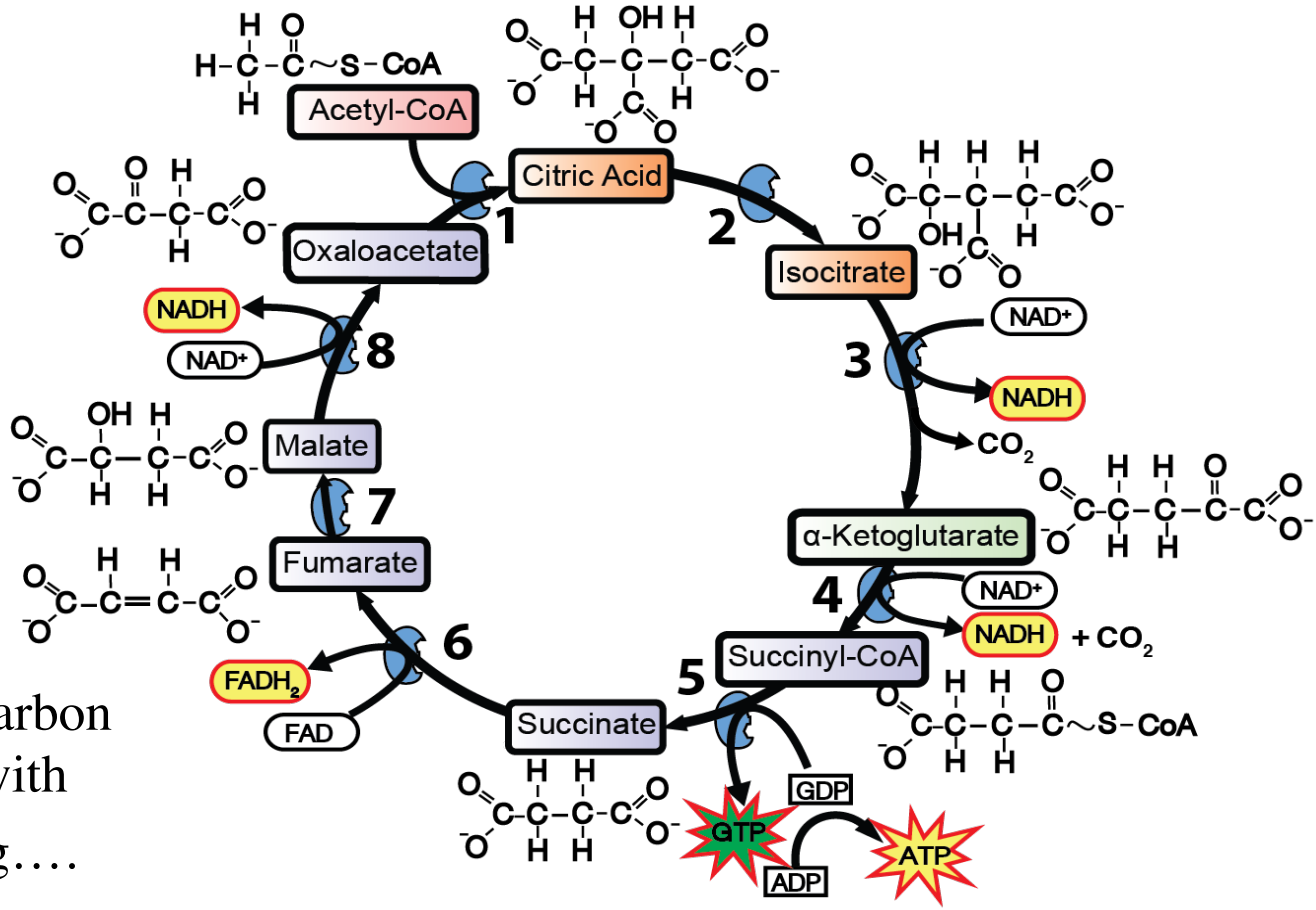


# Talk it through, noting

1. The *number* of carbons in the substrates. 2. How the substrates *change*. 3. What gets *reduced*, what gets *oxidized*. 4. *Phosphorylations*



# What do you have to know by heart?



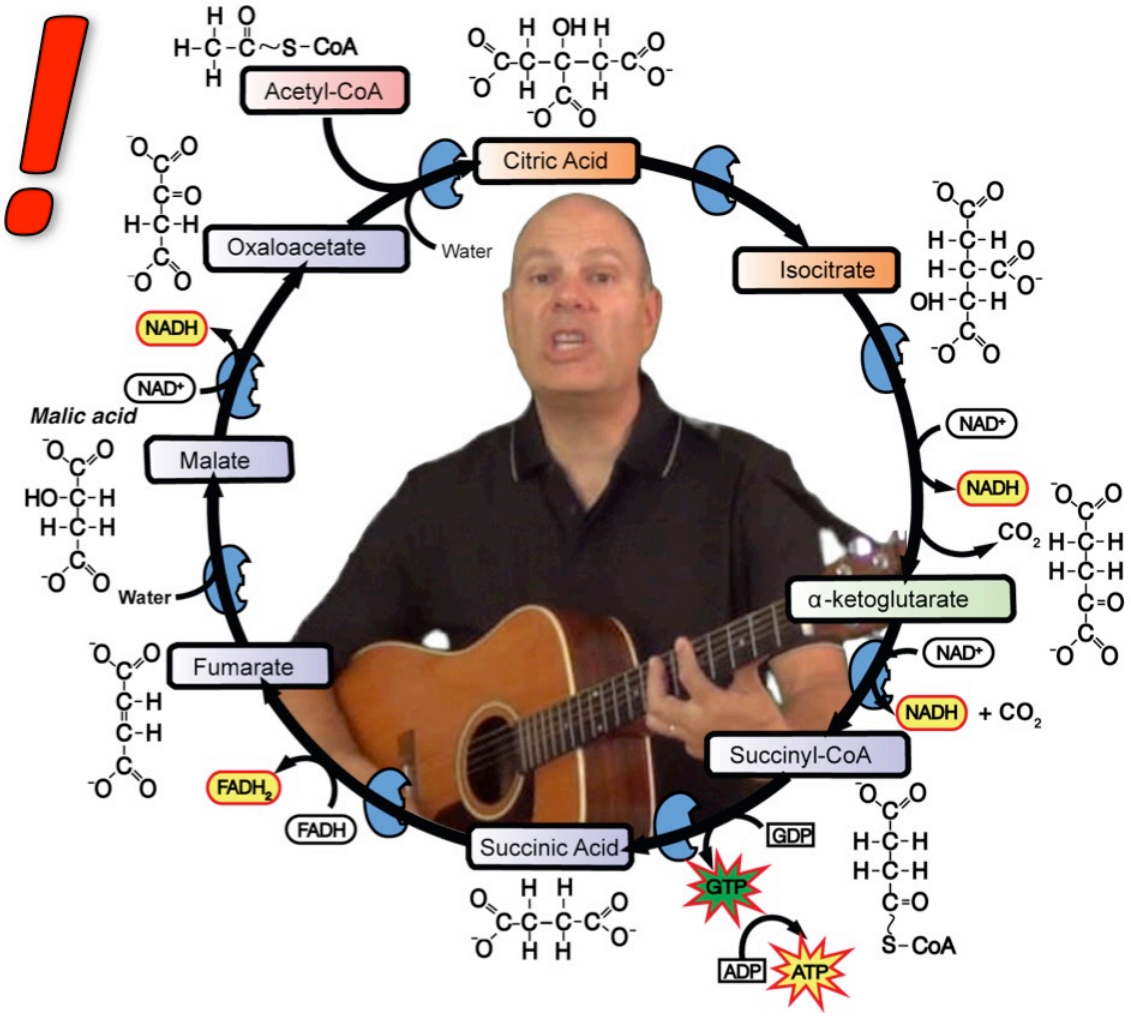

1. Its three names
2. Oxaloacetate: the 4 carbon molecule that binds with
3. Acetyl Co A, creating….
4. Citrate (6C)
5. Number of $FADH_2$, NADHs, and ATPs produced for each acetyl CoA that comes in.

# Krebs!

ATP

NADH

$FADH_2$

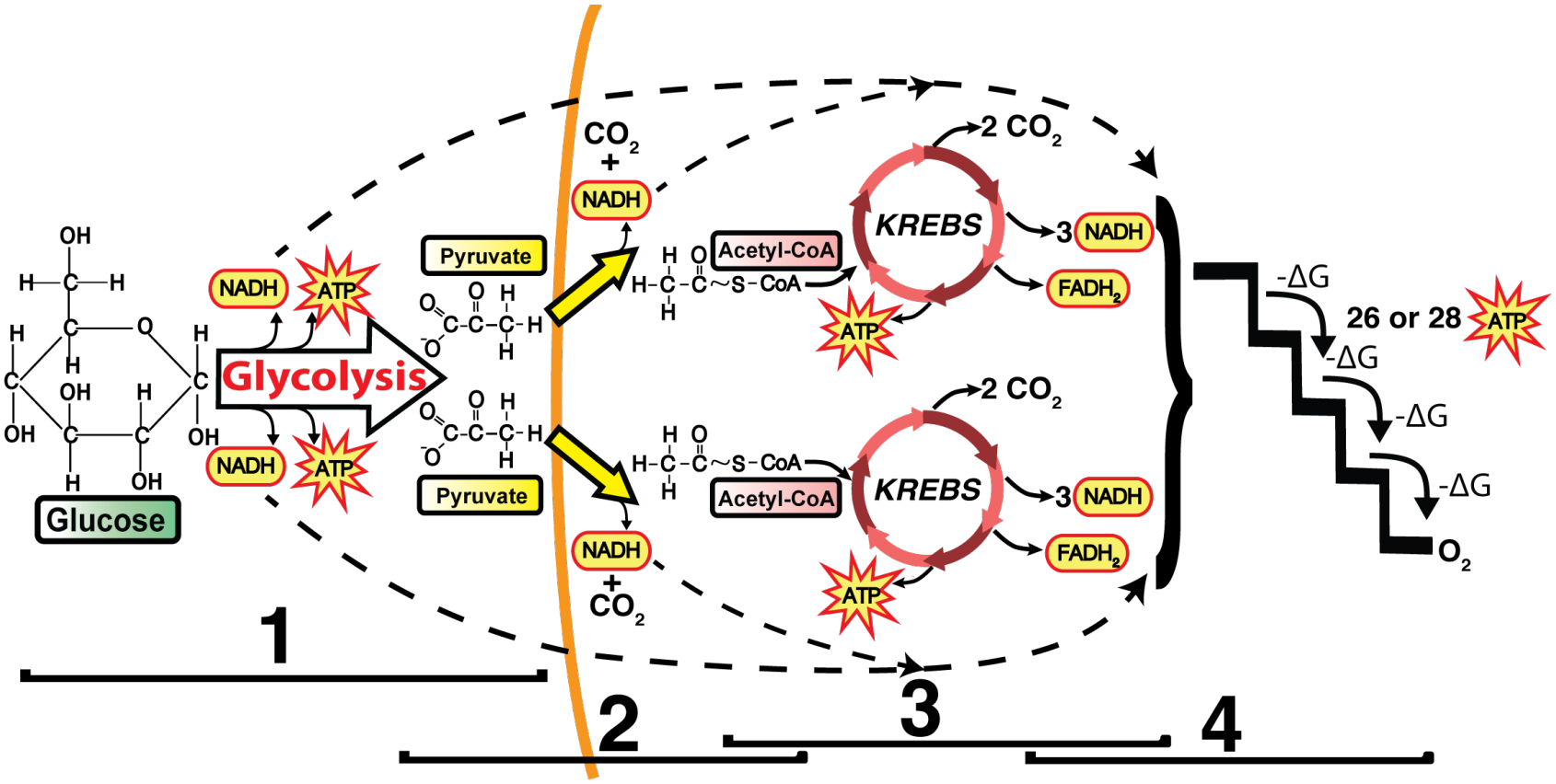



- Cellular Respiration: A Musical Review

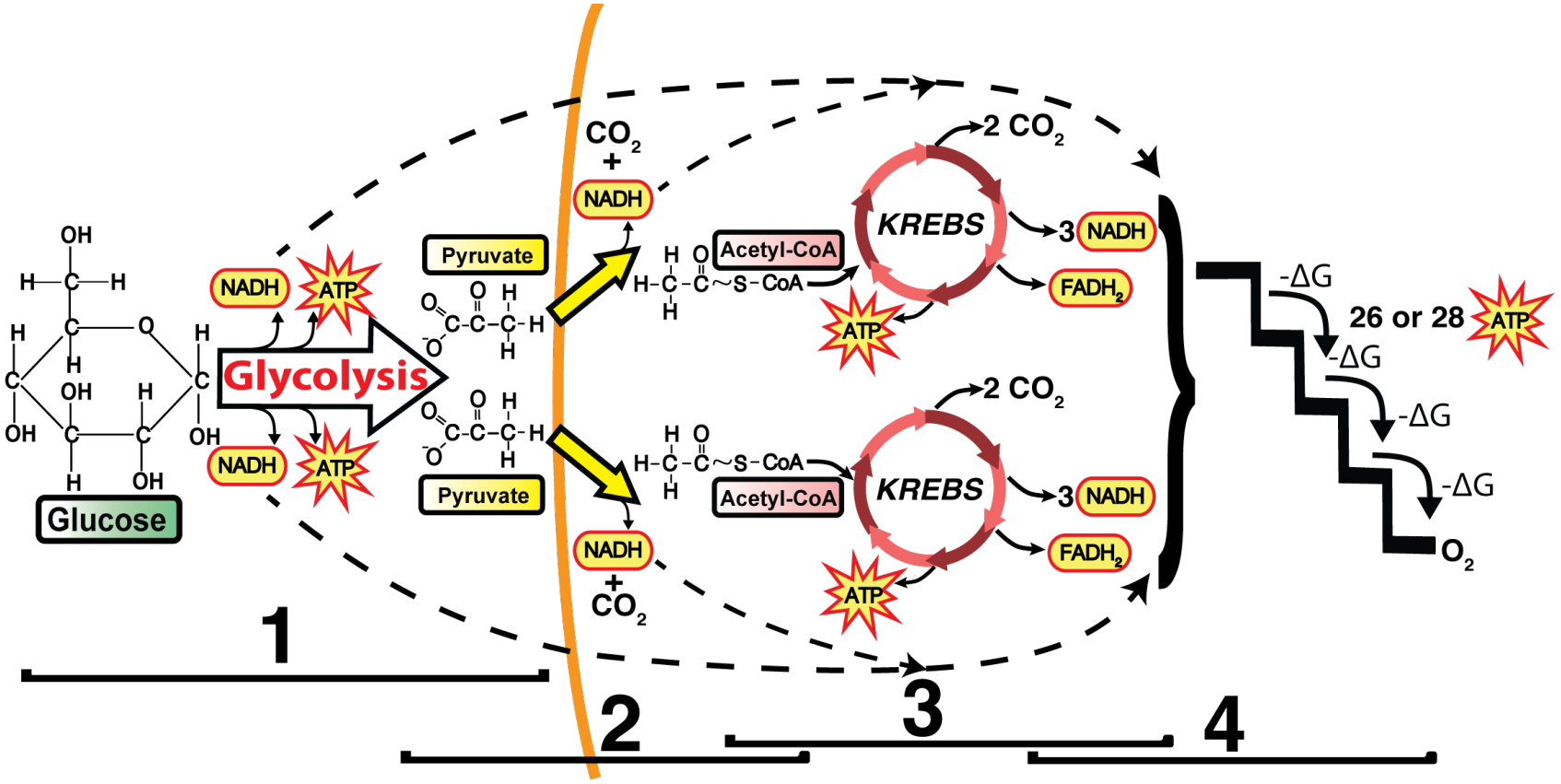
# Part 5

Electron Transport Chain

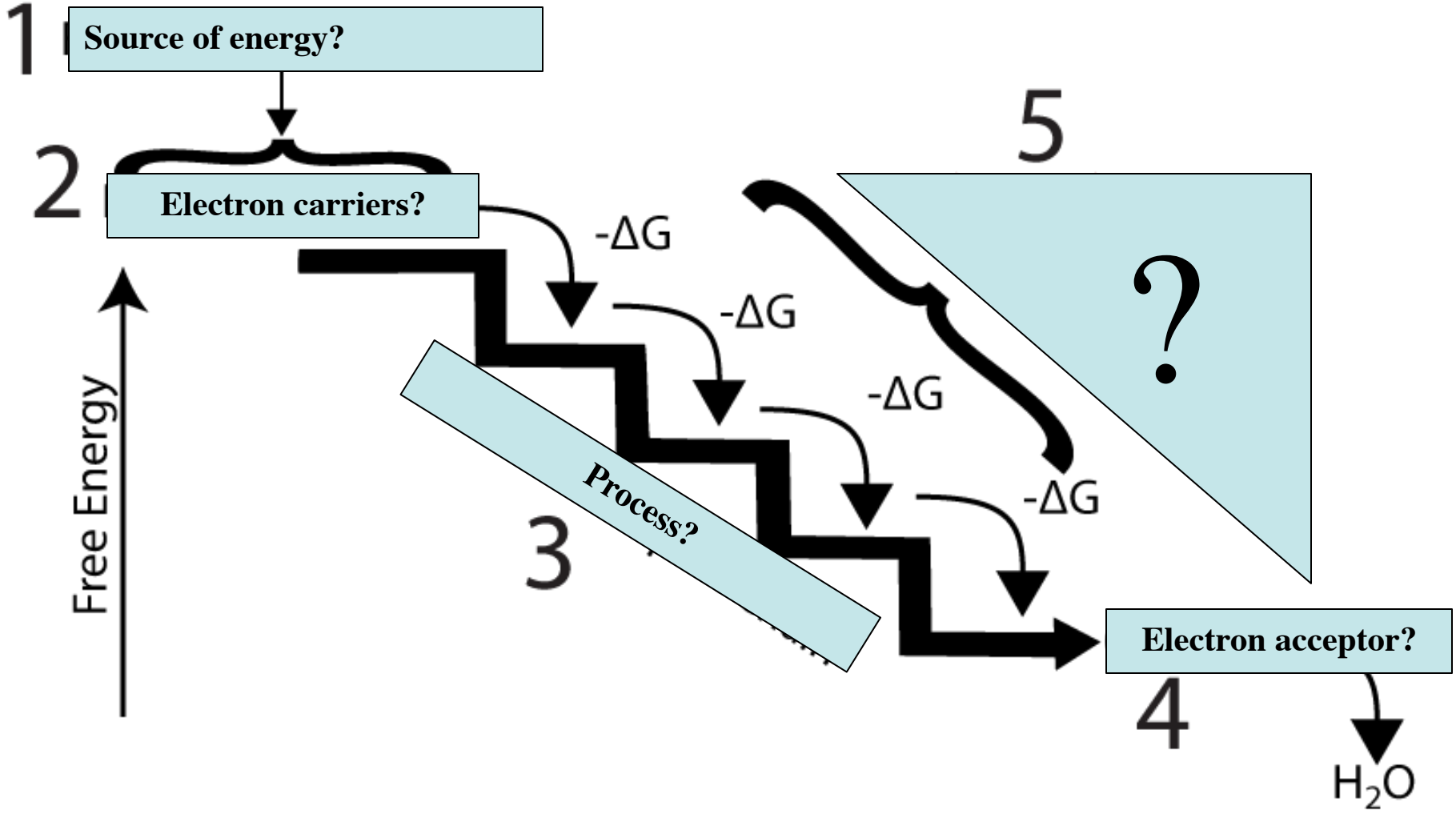
# Take out your lecture notes from yesterday



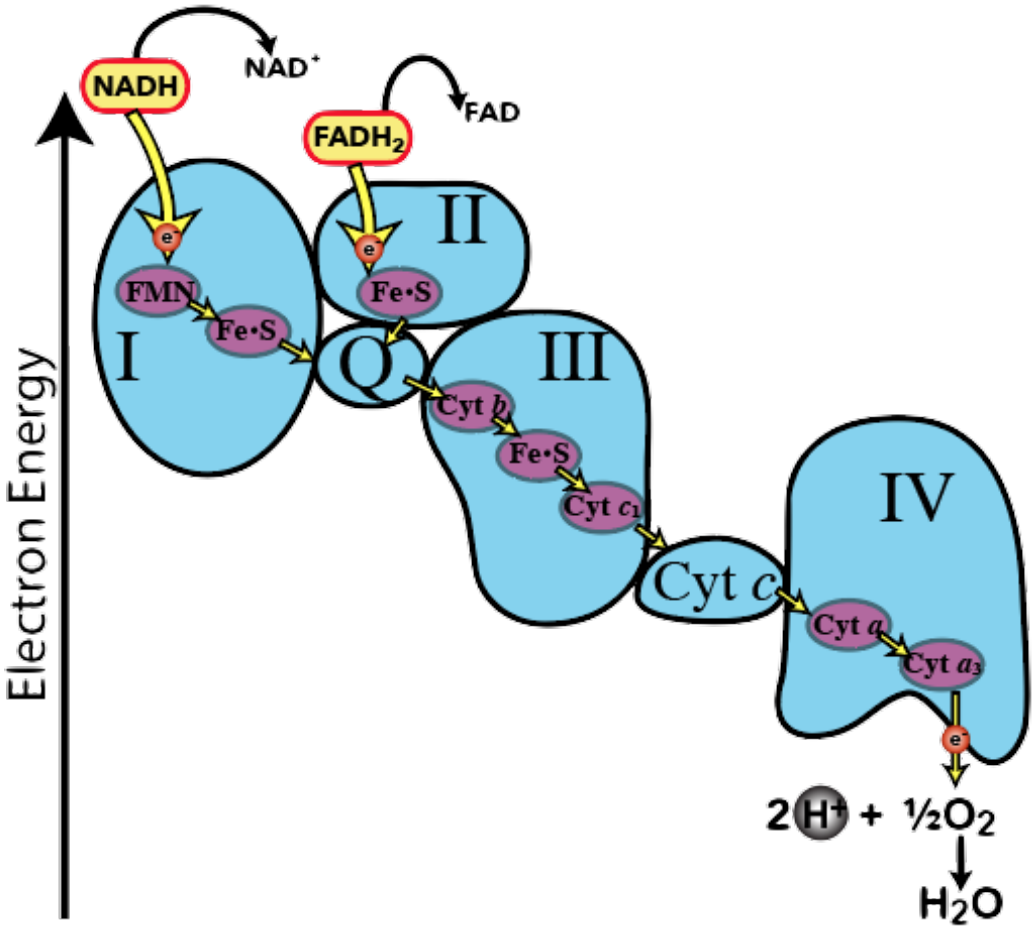
# After Glycolysis, the link reaction, and Krebs…



# NADH and $FADH_2$ are now used to make



# The ETC: Conceptual view




- FUNCTION: powering proton pumps
- Structure:
  - Series of electron carriers, arranged in order of *electronegativity*.
  - Many are *cytochromes*.
- Electrons flow "downhill" from NADH and $FADH_2$ toward oxygen.

# The electron transport chain is in the inner membrane

WRITE SMALL

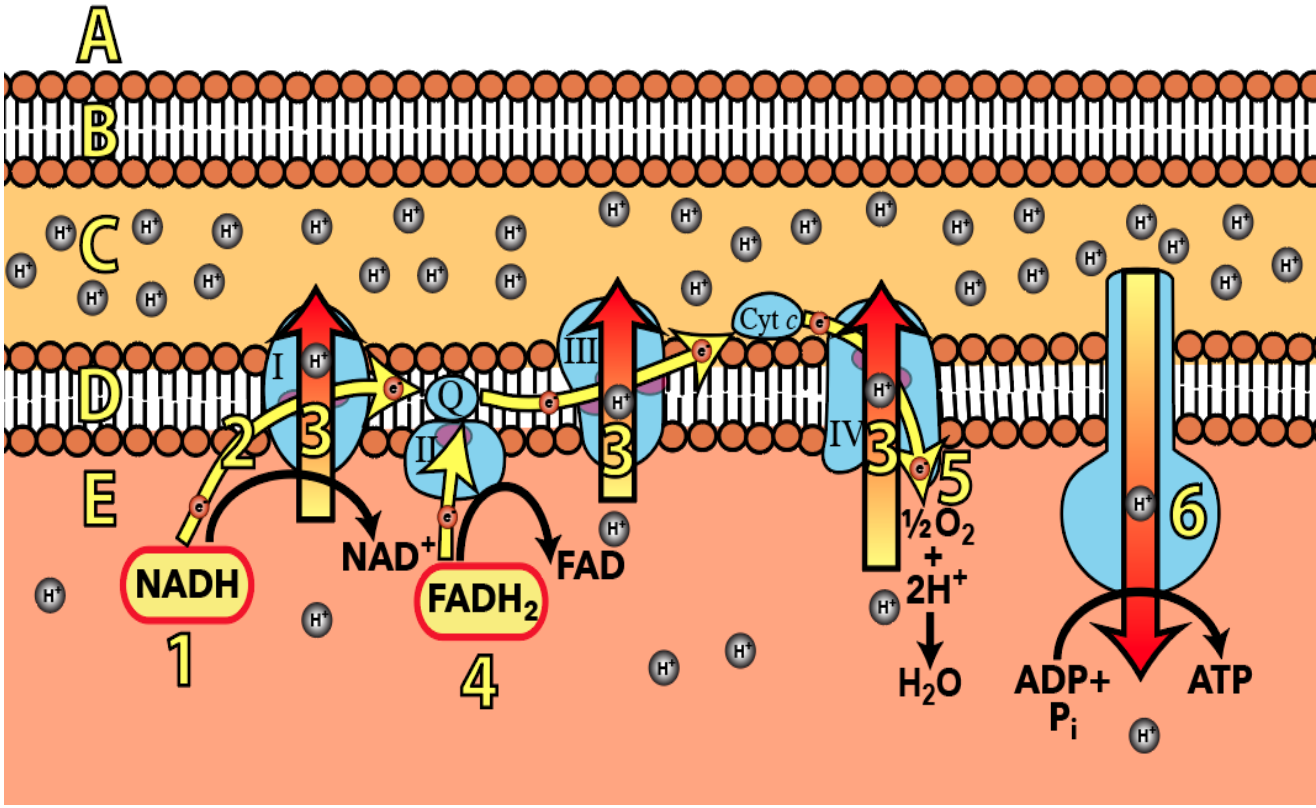
A: cytoplasm

B: outer membrane

C: inter-membrane space

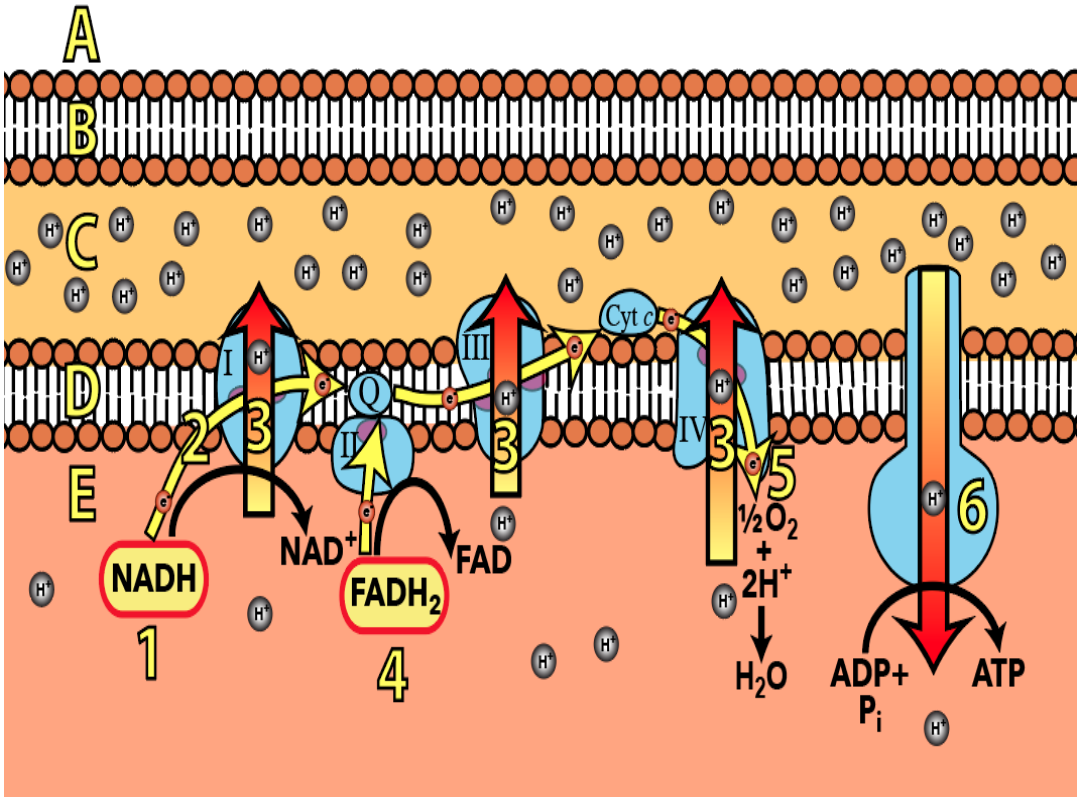
D: inner membrane

E. Matrix



How it works:

1. e⁻s from **NADH** …
2. flow on ETC e⁻ pathway…
3. Powering $H^+$ pumps: pump $H^+$ from **matrix** to i.m.s. (C). This is **active transport**.
4. e⁻s from $FADH_2$ (same as # 1)
5. **$O_2$** is last e⁻ acceptor. Gets reduced to **$H_2O$**.
6. **Protons** diffuse through ATP synthase from i.m.s. to matrix, which powers synthesis of **ATP** from ADP and Pi



*The mitochondrial electron transport chain*

*Uses electron energy for pumping protons*

*From the mitochondrial matrix to the intermembrane space*

*Increasing proton concentration in that place,*

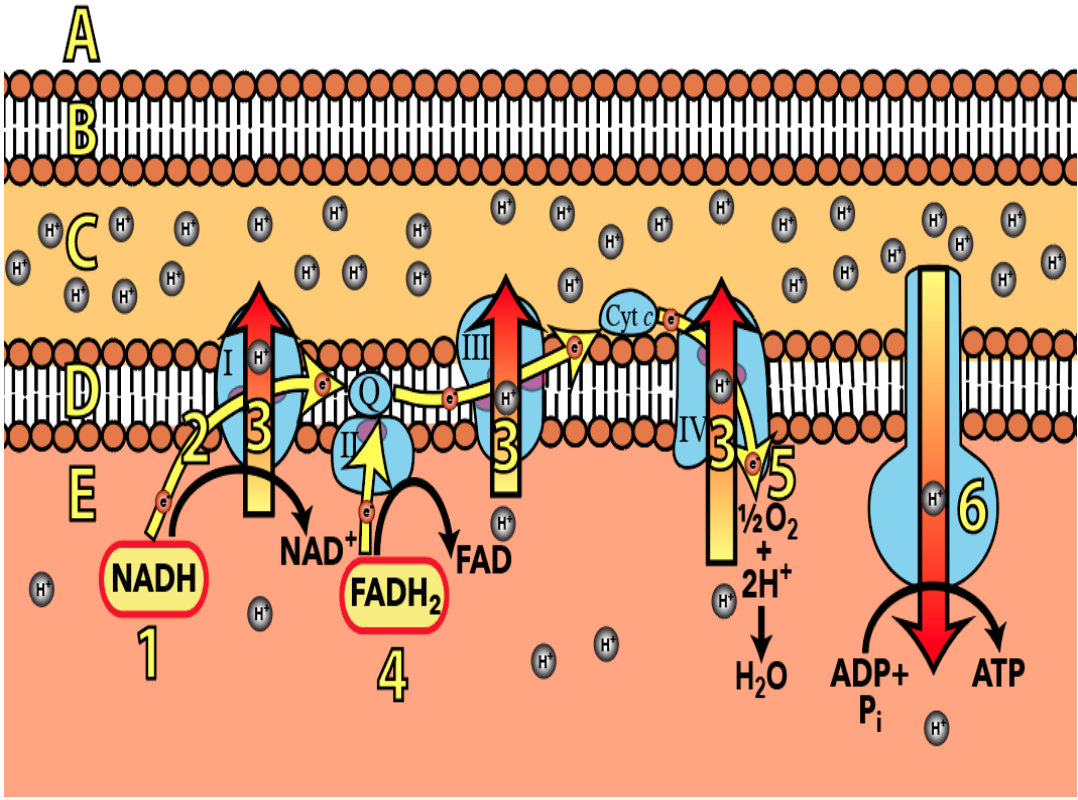
*The only way the protons can escape*

*Is through a channel and an enzyme, ATP synthase.*

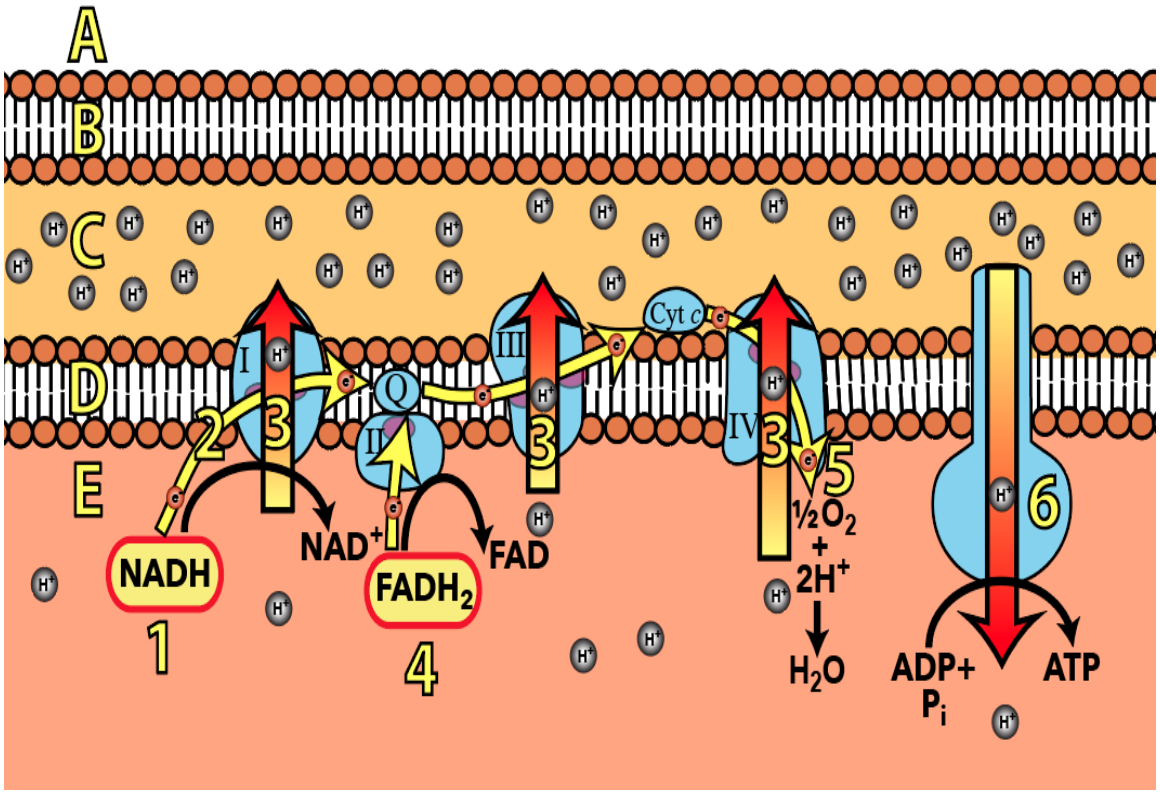
*Which uses diffusing protons' kinetic energy*

*To make ATP, from ADP and P*

Or you can sing…

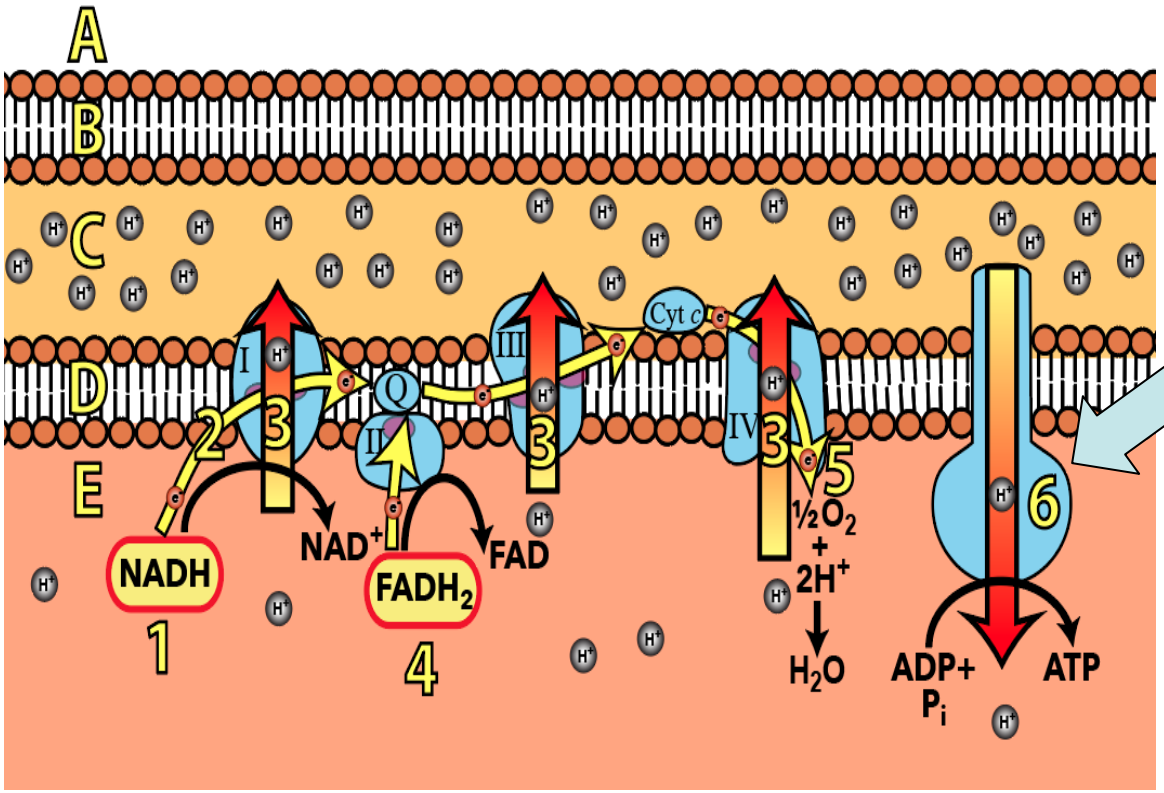


Pumping $H^+$ creates a huge *potential energy gradient* across the inner mitochondrial membrane…




- Concentration gradient
- Voltage gradient (based on electrical charge difference)

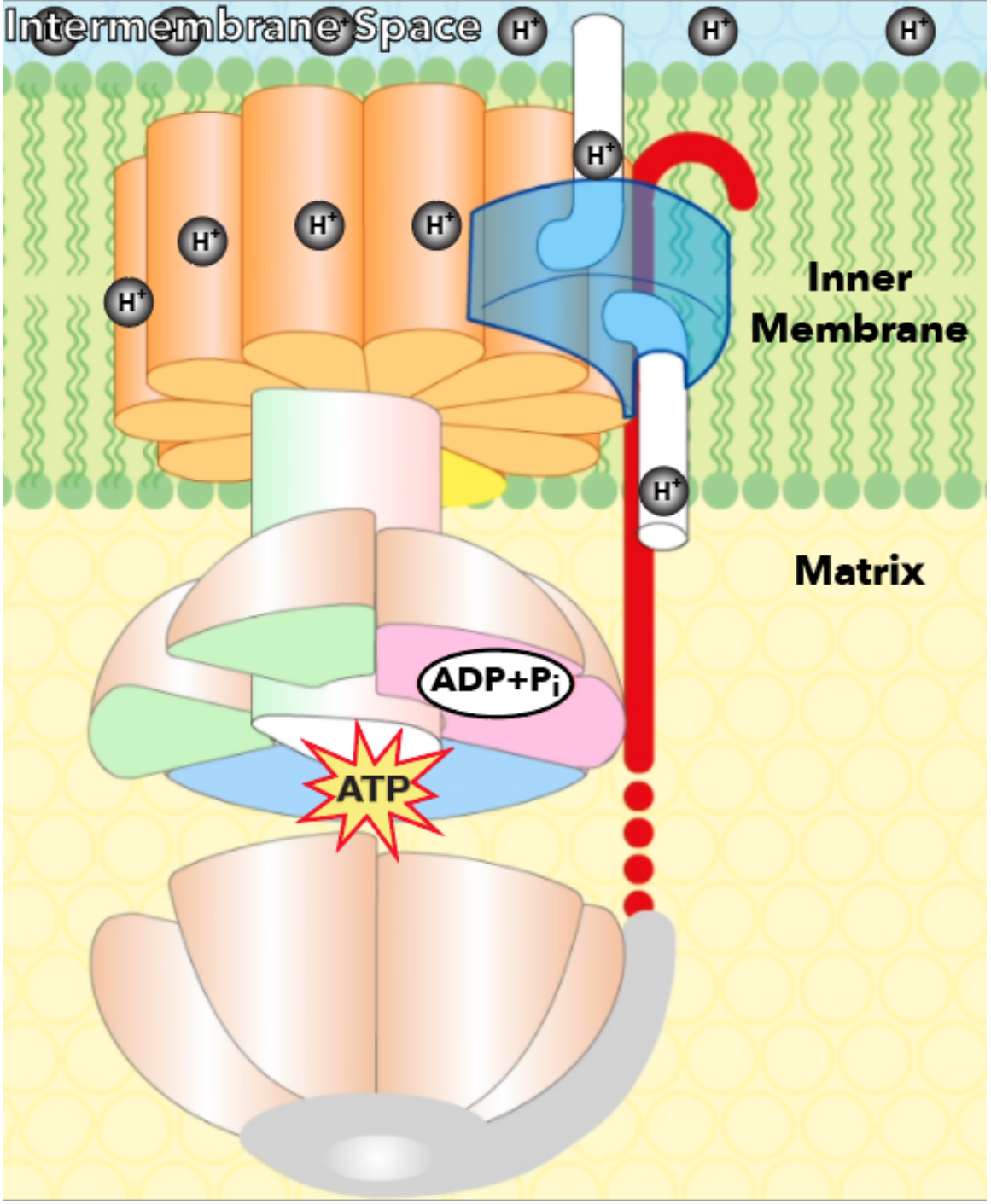
What's the only one way out for protons?



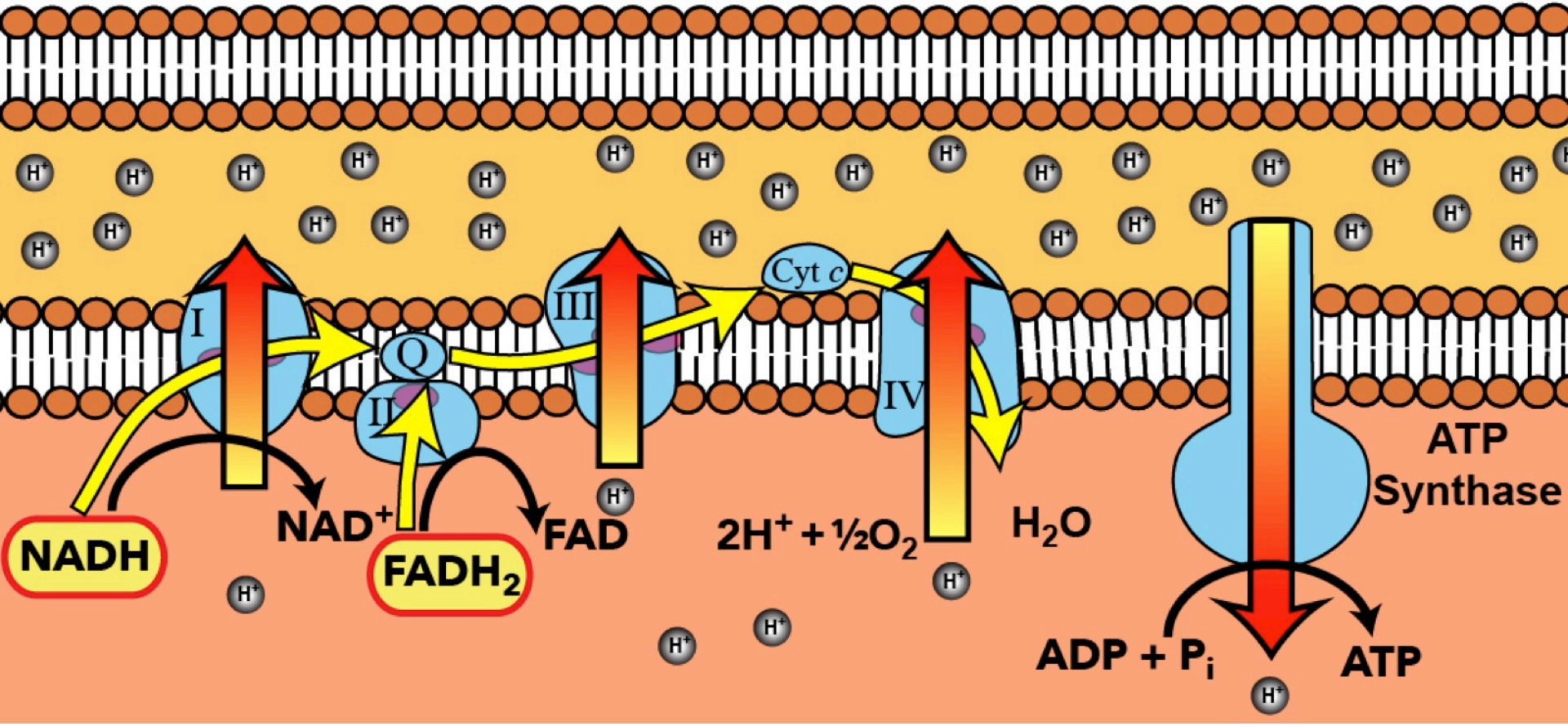

ATP Synthase

# ATP Synthase

- Enzyme *and* channel
- Uses the kinetic/ electrochemical energy of diffusing $H^+$ to combine ADP and $P_i$ into ATP
- $H^+$ flow through ATP synthase is called *chemiosmosis*.

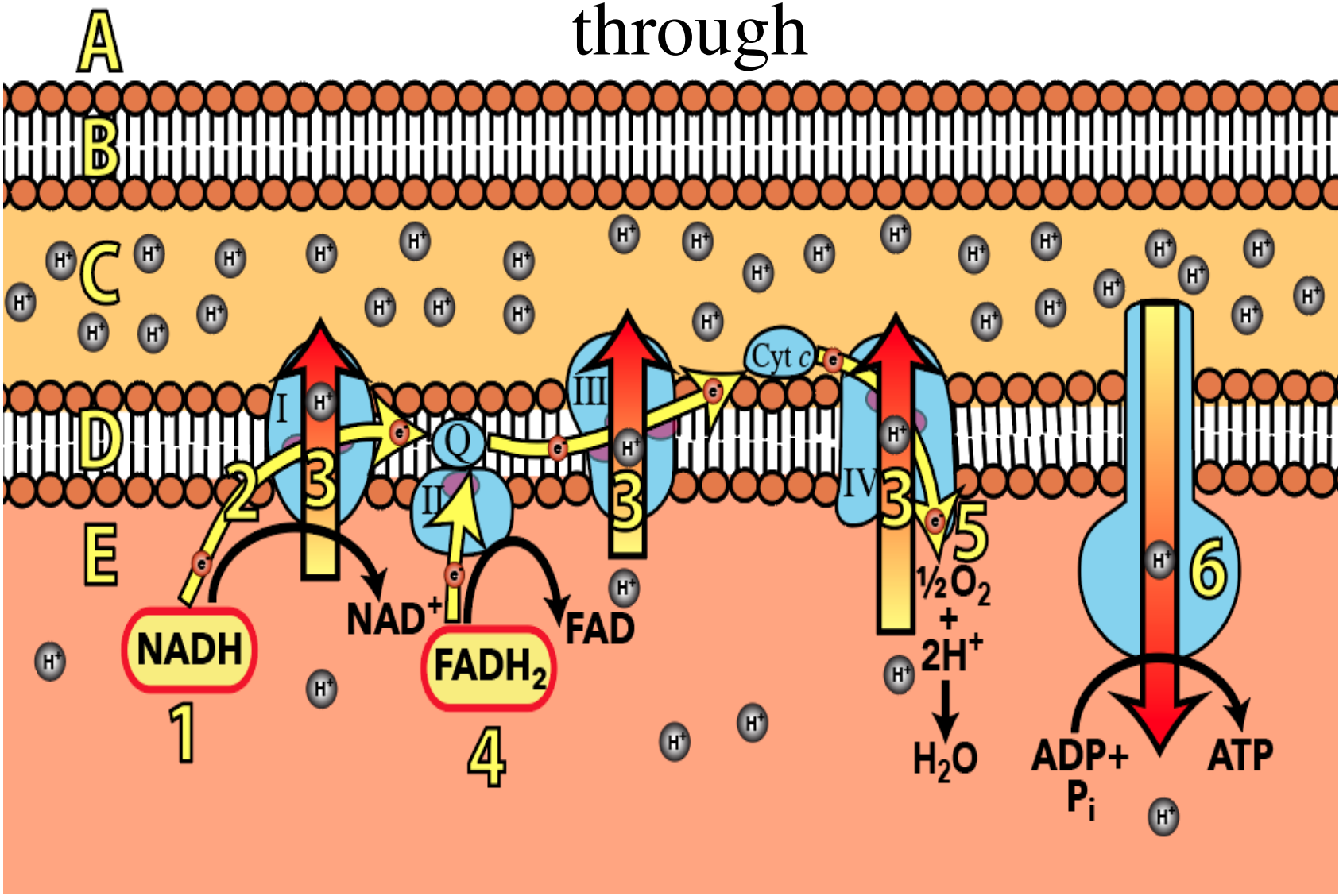


# Electron Transport Chain

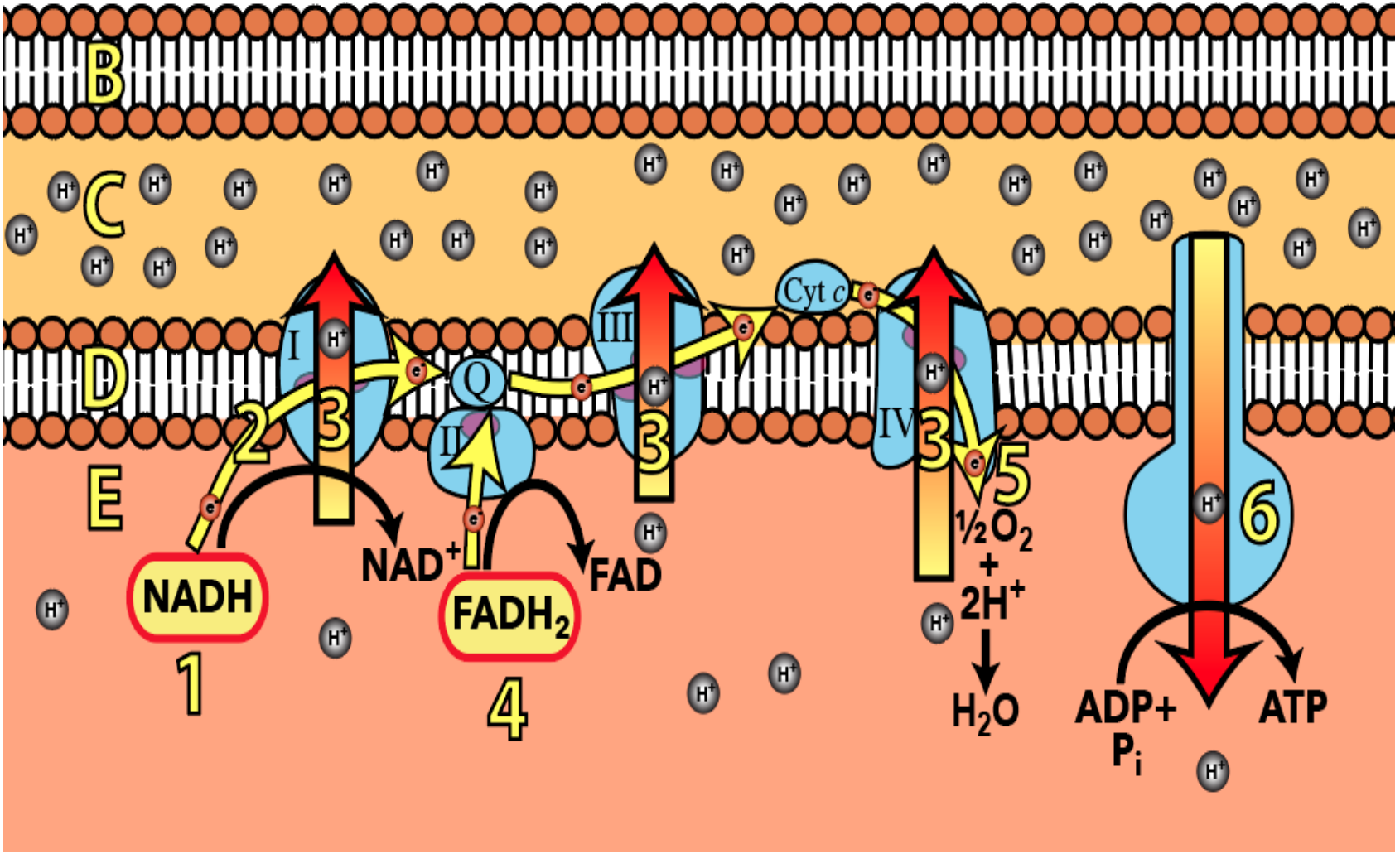



Cellular Respiration: A Musical Review

# The ETC and chemiosmosis: Talk it through



# Now write it out: how is ATP generated through oxidative phosphorylation?



# Part 6

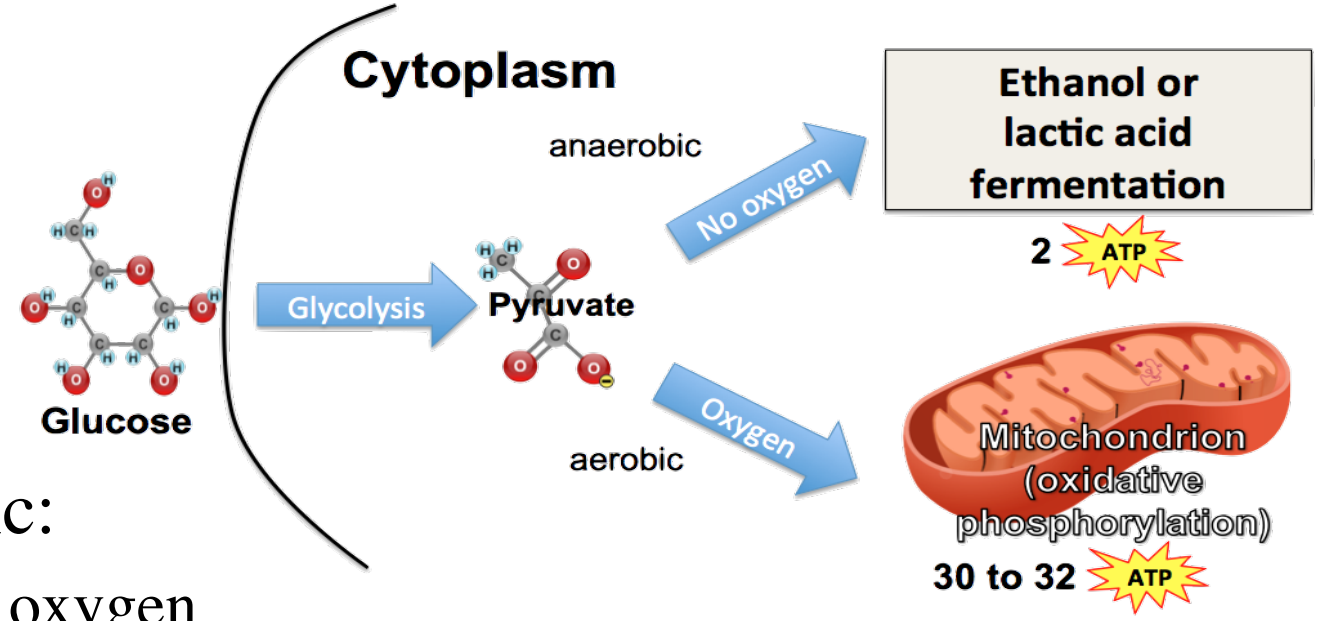
Anaerobic respiration/fermentation

# What do these three things have in common?



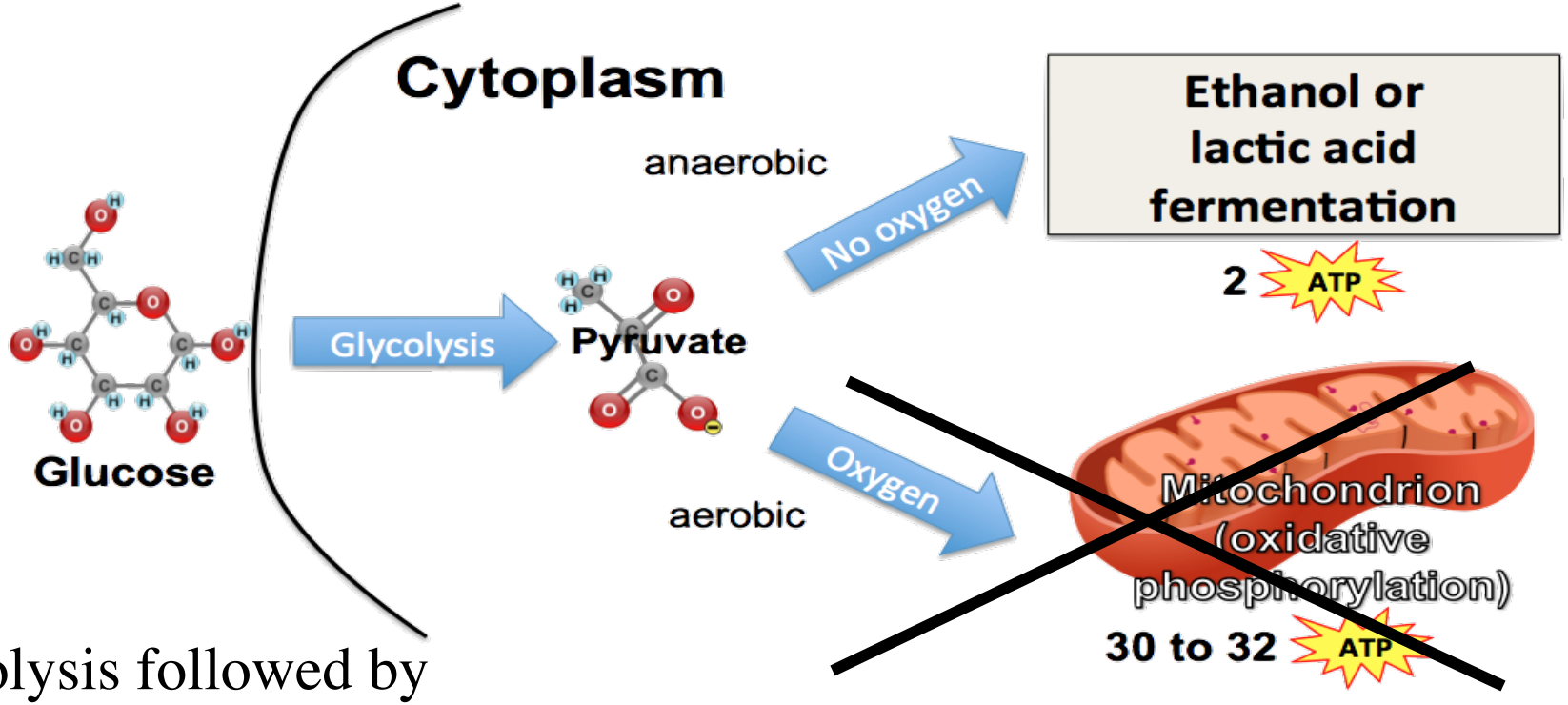
THEY ALL INVOLVE FERMENTATION/ANAEROBIC RESPIRATION

# Aerobic v. Anaerobic respiration




- Aerobic:
  - with oxygen
  - Sustainable indefinitely
  - Walking, long distance sports
- Anaerobic
  - no oxygen
  - Very short term
  - Sprinting, lifting weights

# Fermentation

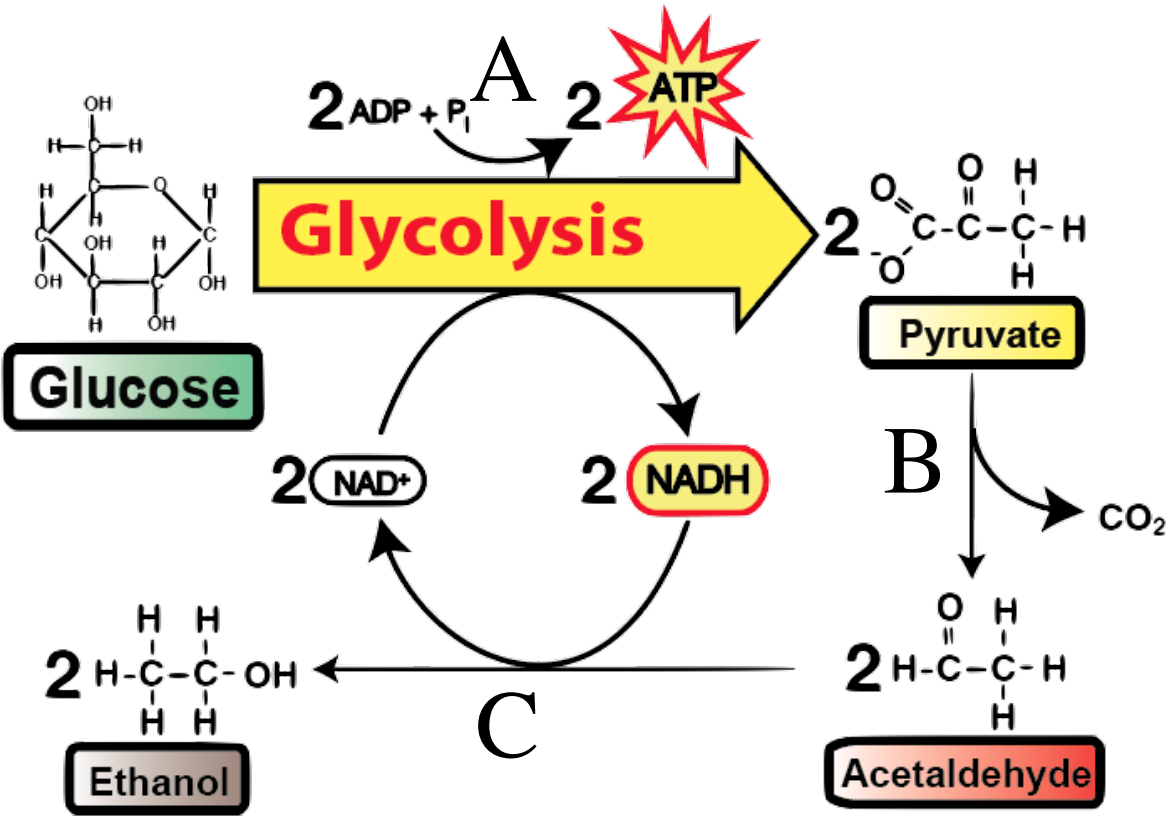



1. Glycolysis followed by regeneration of $NAD^+$ so that glycolysis can continue.
2. No Krebs or oxidative phosphorylation.
3. Happens when there's
    1. A lack of oxygen
    2. A lack of enzymatic pathways.

4. Why: Two ATP are better than none, and glycolysis can't continue without $NAD^+$
5. Two types:
    1. Alcohol
    2. Lactic Acid

# Alcohol fermentation demonstration

# Alcohol Fermentation




A: glycolysis

B: remove $CO_2$ -> acetaldehyde

C: Reduce to ethanol/ oxidize NADH->$NAD^+$

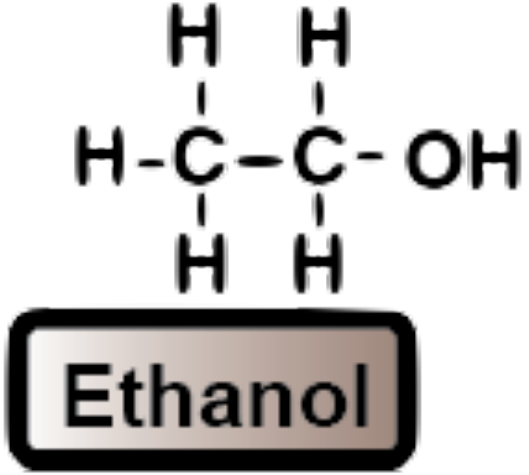
# Nutrition Facts

Serving Size 12 oz (354.88 ml)
Servings Per Container 1

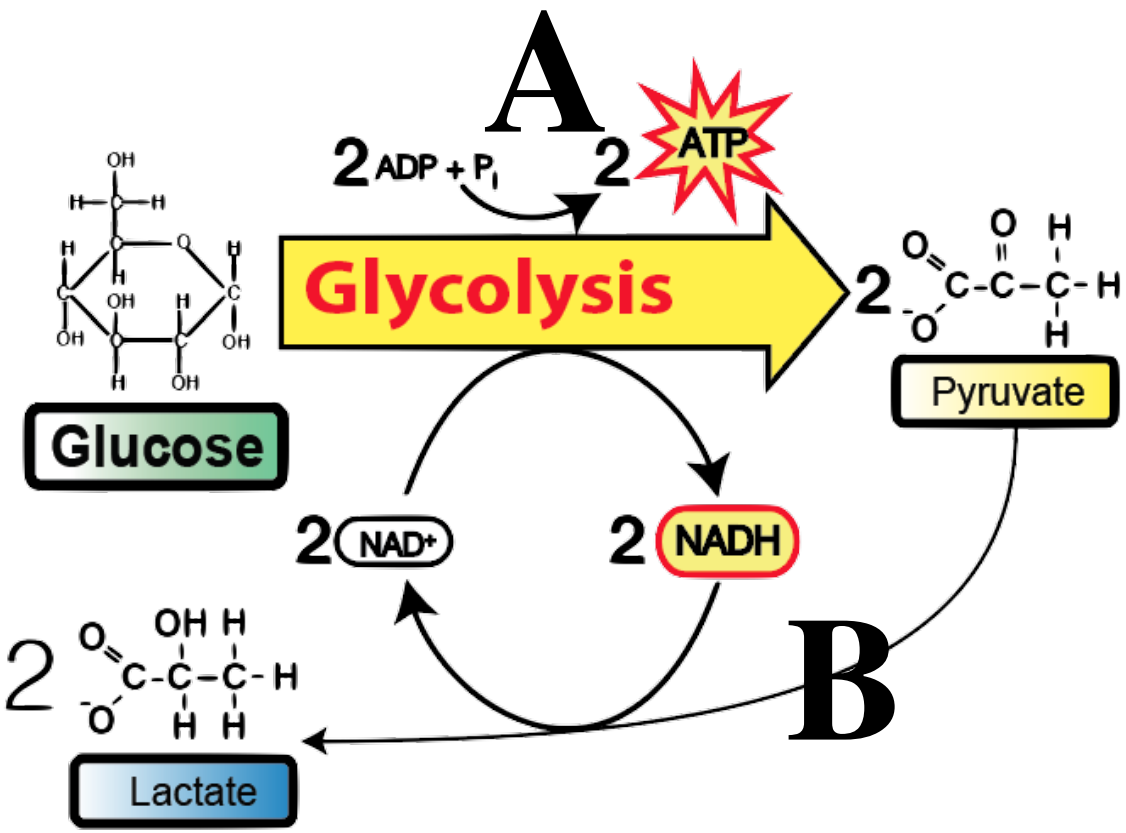
| Amount Per Serving | |
|---|---|
| **Calories** 150 | Calories from Fat 0 |
| | **% Daily Value*** |
| **Total Fat** 0g | 0% |
| Saturated Fat | 0% |
| Trans Fat | 0% |
| **Cholesterol** | 0% |
| **Total Carbohydrate** 13g | 4.7% |
| Fiber 8g | 40% |
| **Protein** 1g | |

Contains significant amounts of deliciousness, potassium, hops, magic, selenium, barley, niacin, taste, magnesium, phosphorus, happiness, and GOLD!

*Percent Daily Values are based on a 2,000 calorie diet.


# Lactic Acid Fermentation

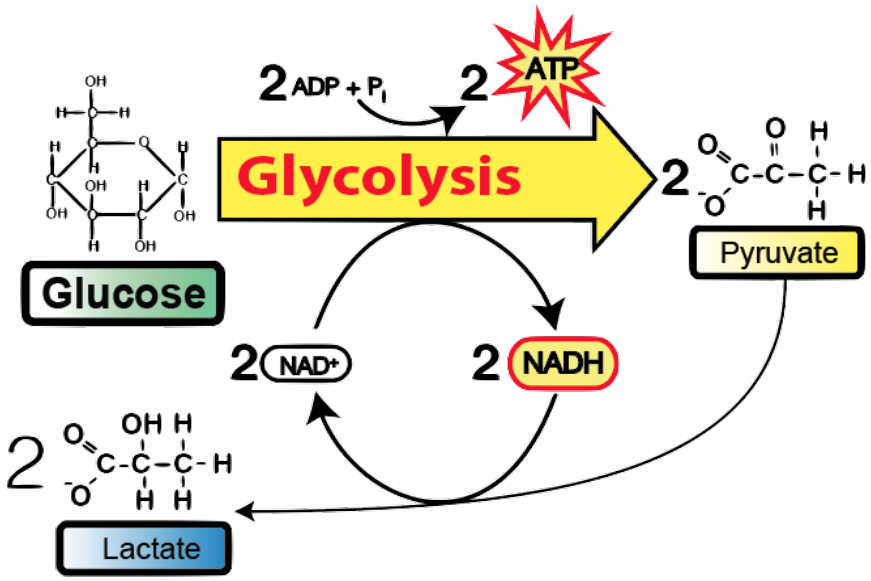



A. Glycolysis

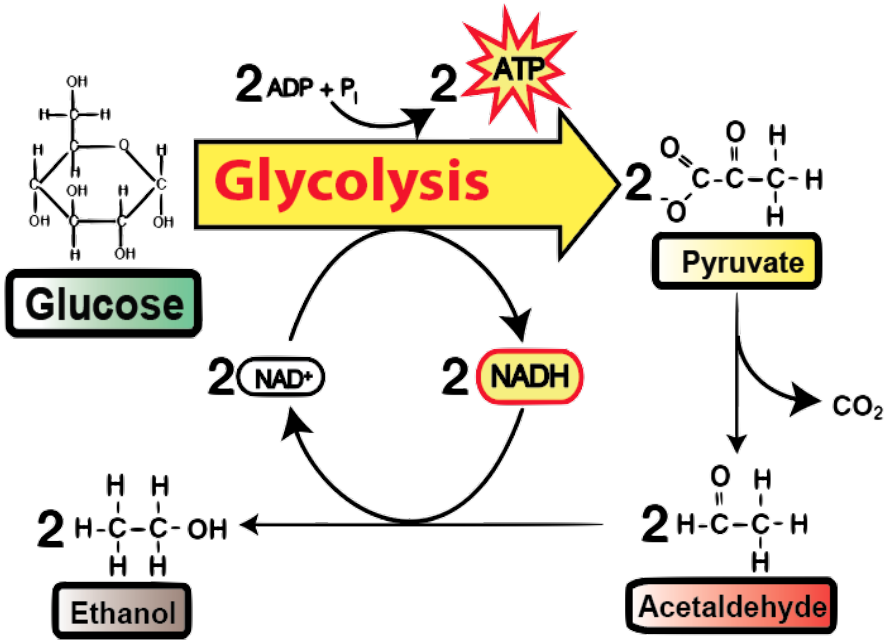
B. Reduce pyruvate to lactate/ oxidize NADH -> $NAD^+$

# Fermentation (1)

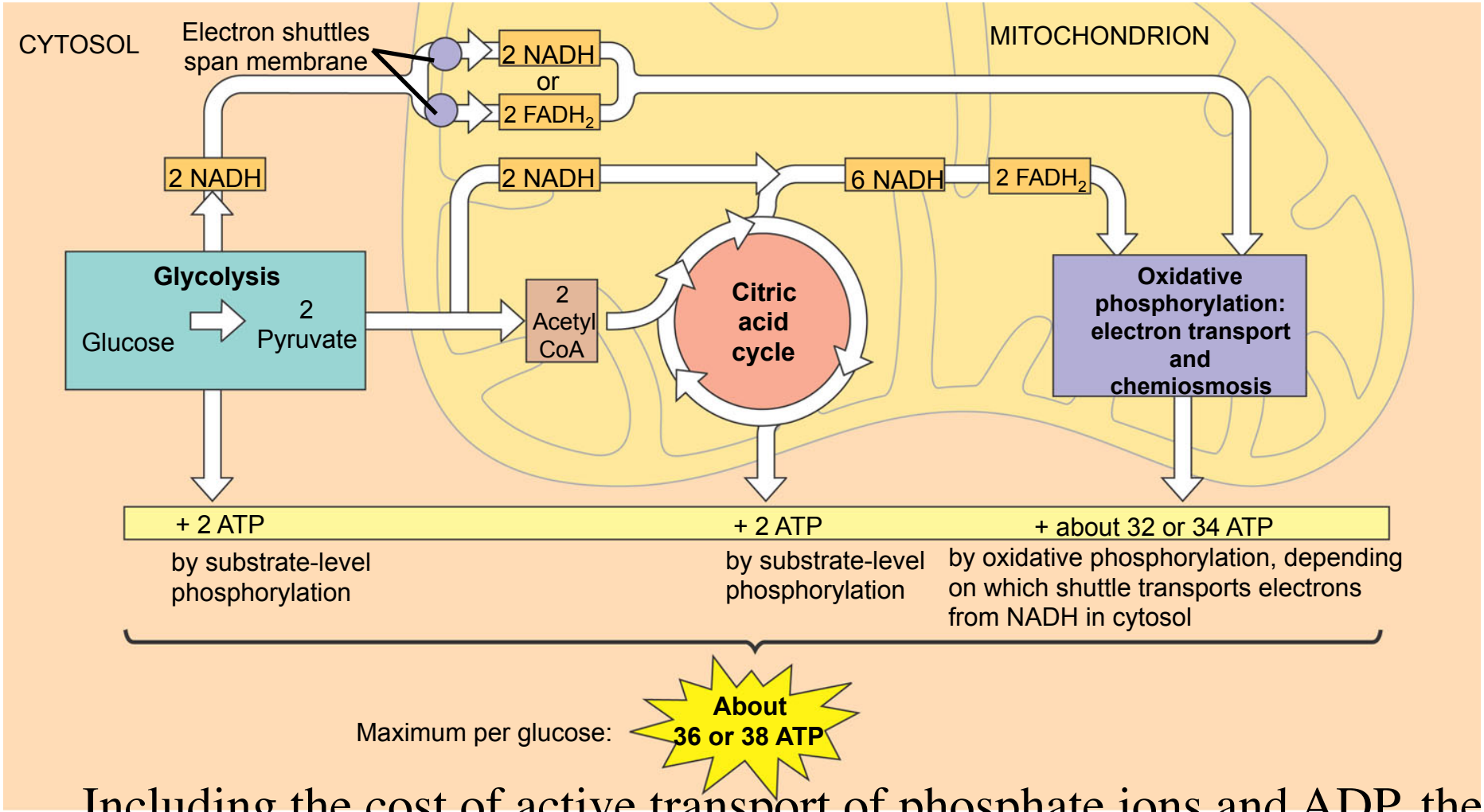
1. Which has more energy: a molecule of pyruvate, or a molecule of lactate? Why?




2. Why can drinking lots of alcohol lead to weight gain?



# Theoretical maximum ATP Yield of Cellular Respiration




Including the cost of active transport of phosphate ions and ADP, the actual yield is **closer to 30**