Chapter 9

CELLULAR RESPIRATION

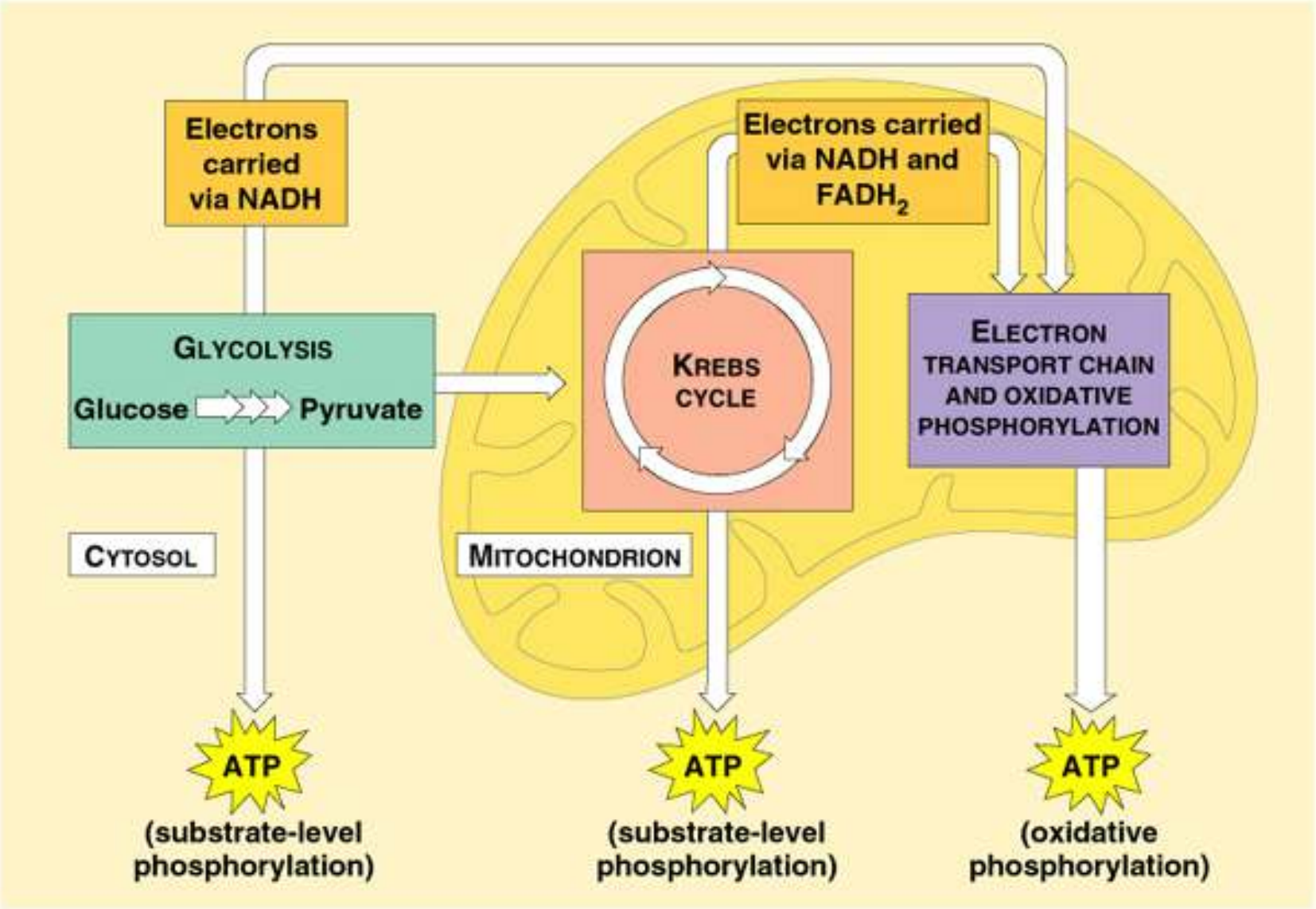
HARVESTING FREE ENERGY

- Photosynthesis takes free energy and puts it into carbohydrates/sugars
- Carbohydrates can be stored for later use; light can not and neither can ATP

- Organisms have developed a variety of enzyme catalyzed reactions that release the free energy found in simple carbohydrates
  - Glycolysis
  - Fermentation
  - Cellular respiration

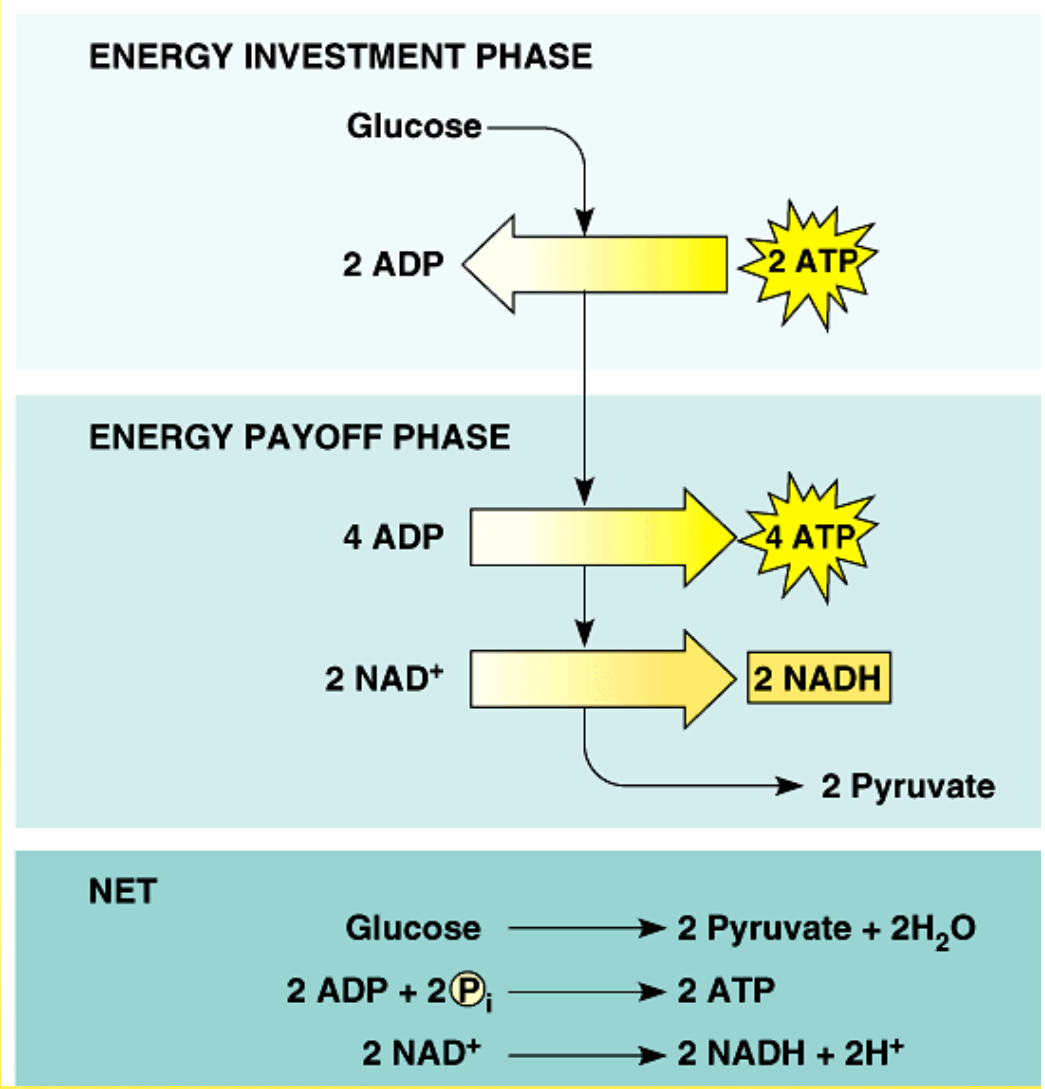
- Now that we have learned how energy is captured, transferred and stored, its time to learn how its actually USED!!!
- Photosynthesis stored energy in carbohydrates.
- Cellular respiration breaks those carbohydrates down.

OVERVIEW OF RESPIRATION



STEP 1: GLYCOLYSIS

- Every living thing does glycolysis
- Begins with glucose
- Chemical bonds are broken and rearranged
- Products
  - ATP
  - NADH
  - Pyruvate

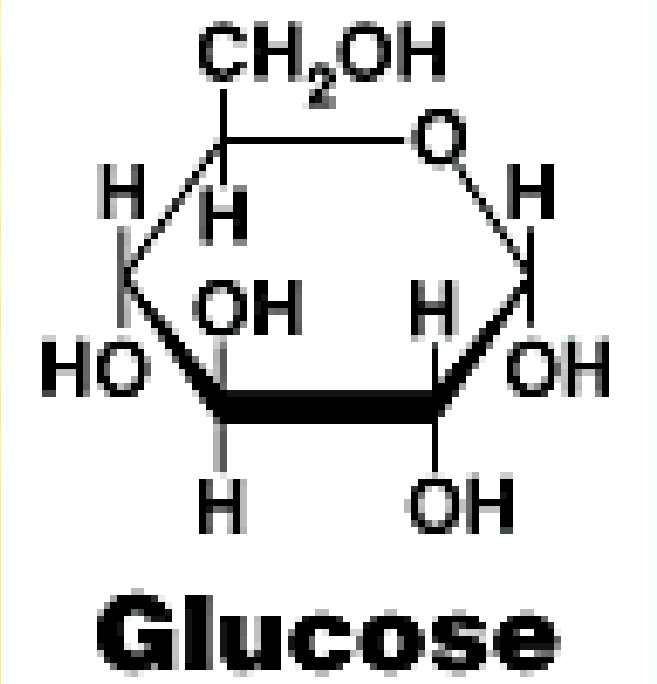


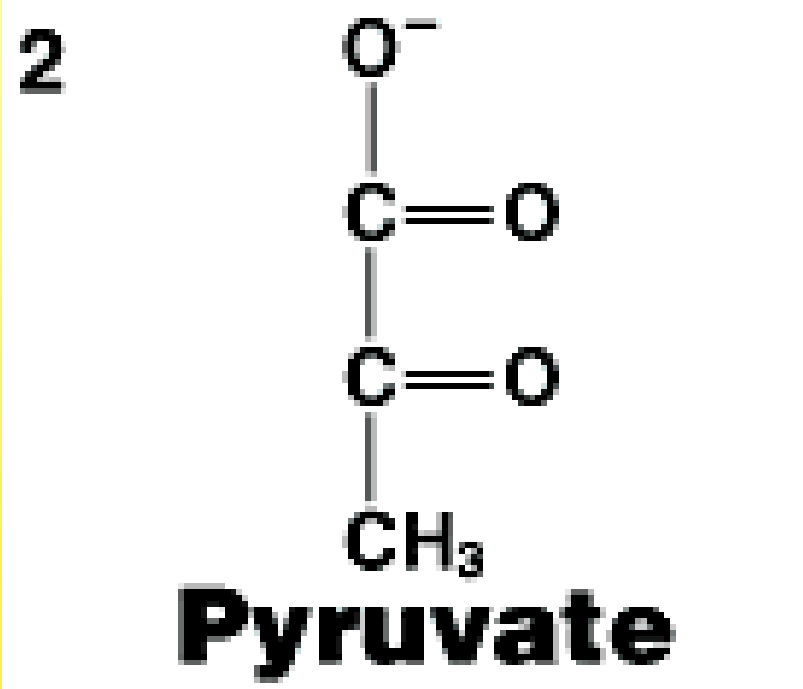
WHAT IS NADH?

- An energy transporting molecule
  - Transports energized electrons
  - Kind of like NADPH

WHAT IS PYRUVATE?

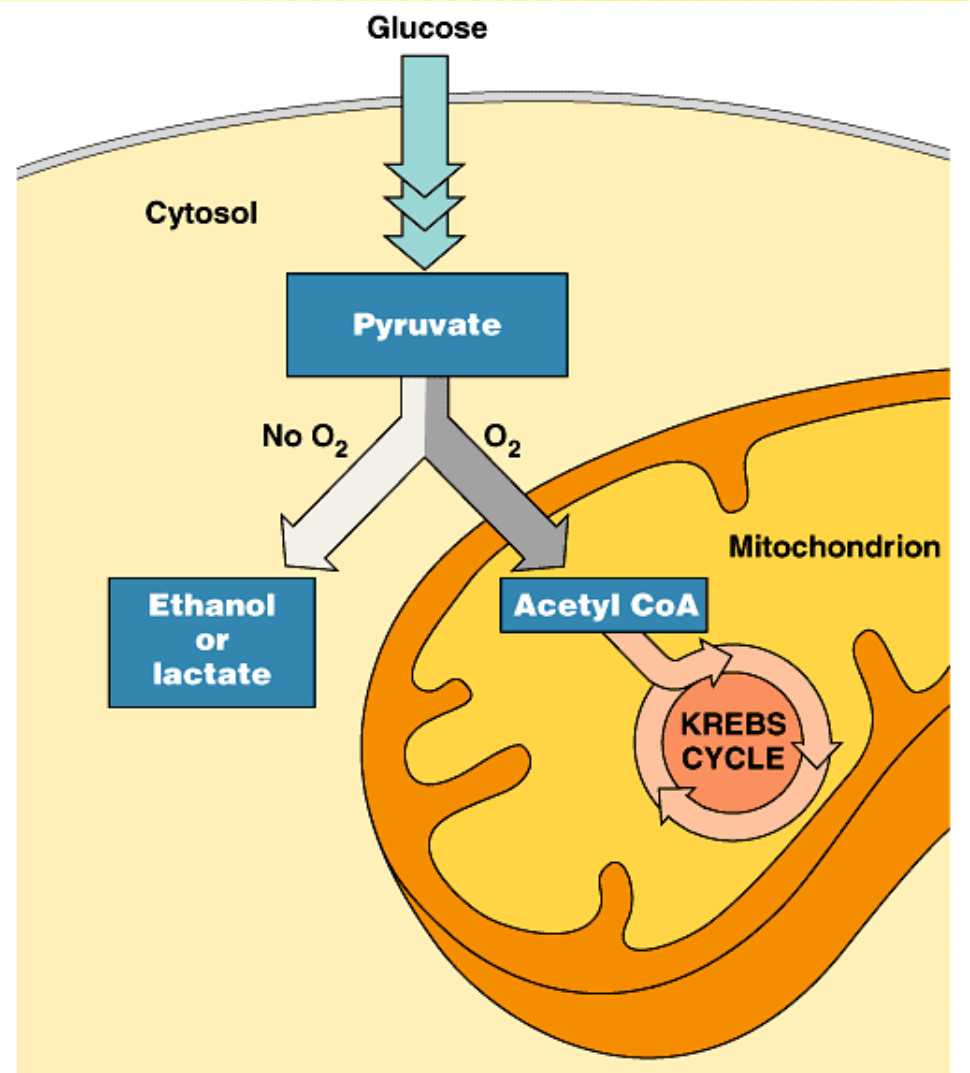
- Glycolysis occurs in the cytosol
- Pyruvate can travel inside of the mitochondrion for additional oxidation
  - Glucose can't





A FORK IN THE ROAD

- Fermentation vs. Cellular Respiration
  - Fermentation: breaking down sugars in the absence of O_2
  - Cellular Respiration: breaking down sugars in the presence of O_2
    - O_2 used as a reactant to break down sugars
  - Oxygen determines which metabolic pathway occurs
    - Aerobic vs. anaerobic

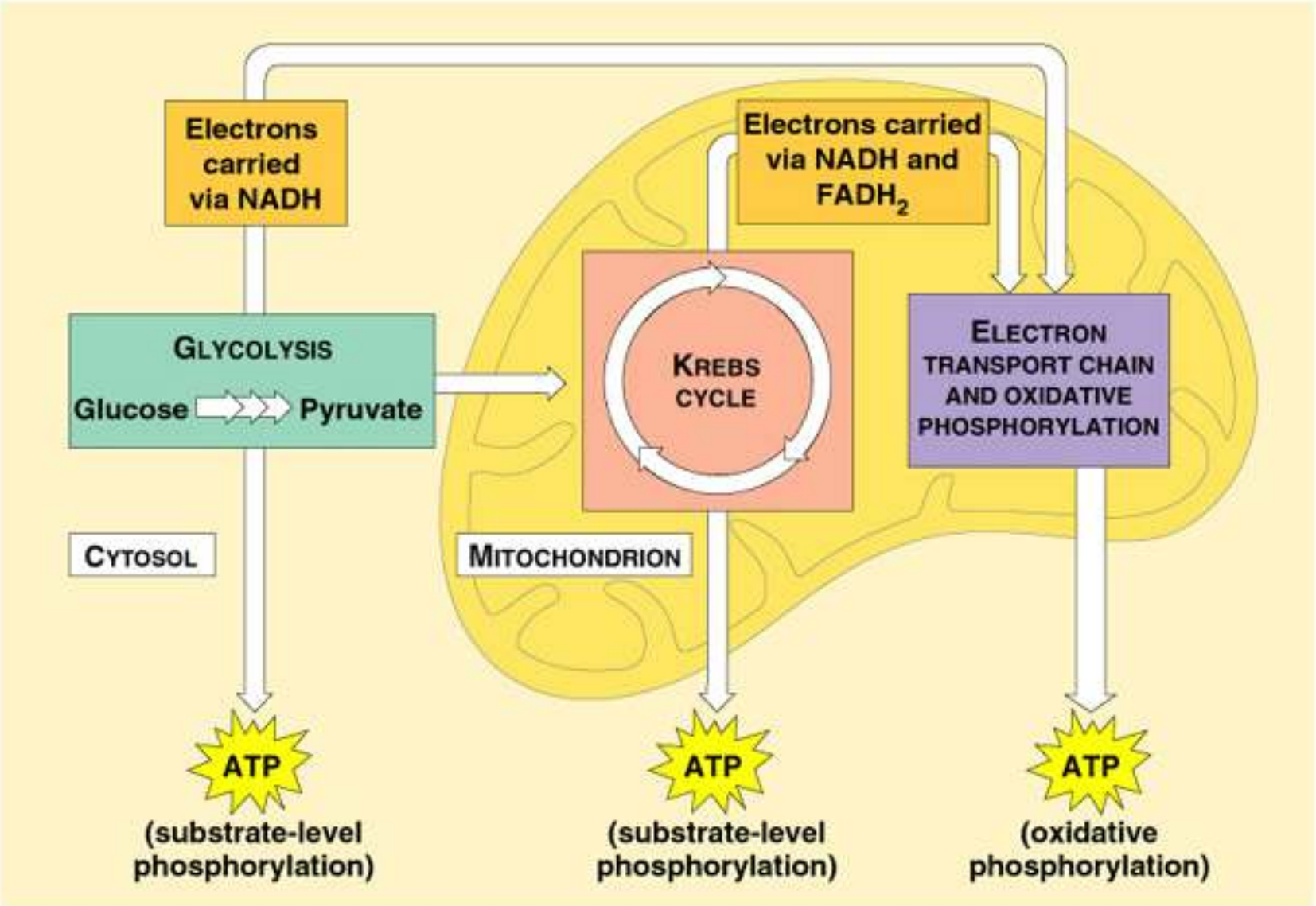


BY THE WAY…

- This is why you breathe!

O_2

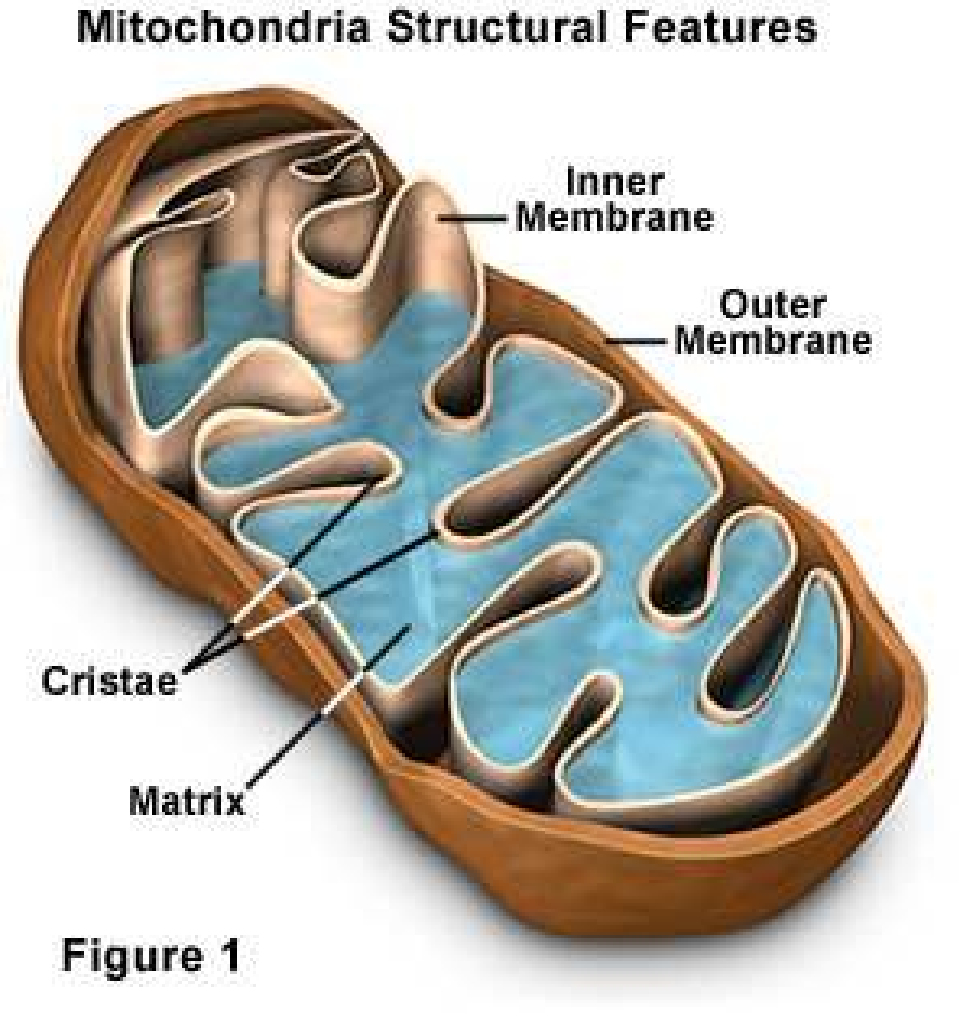
LET'S TALK CELLULAR RESPIRATION FIRST



REVIEW OF STRUCTURE OF THE MITOCHONDRION

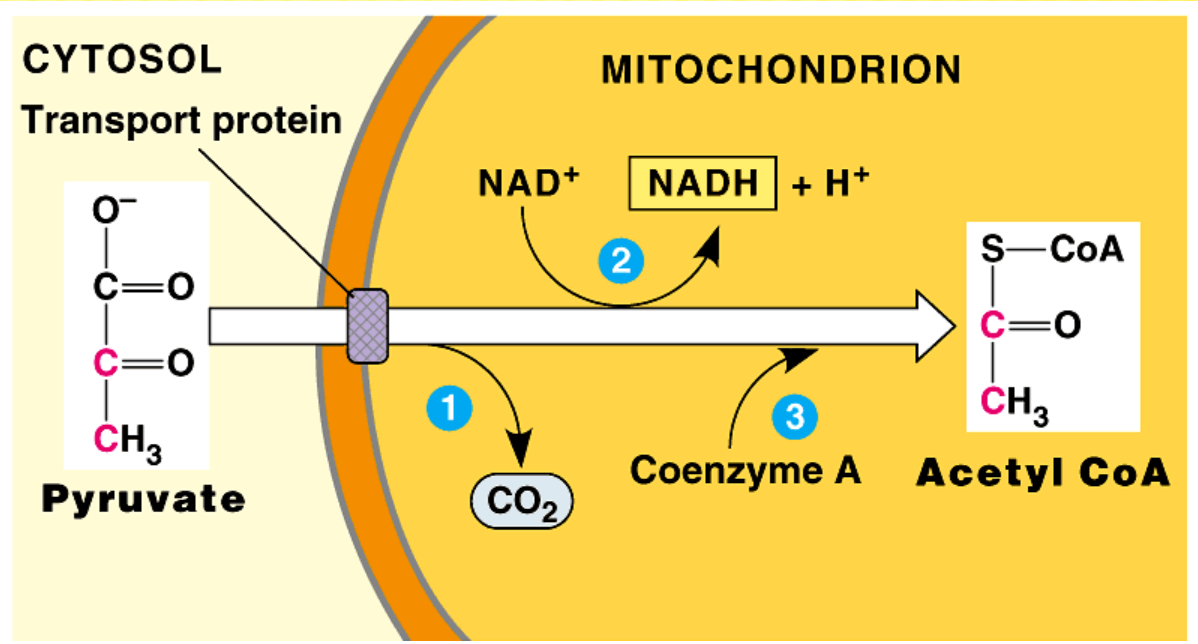
- Pyruvate heads to the mitochondrion for the Citric Acid Cycle (aka the Krebs Cycle)

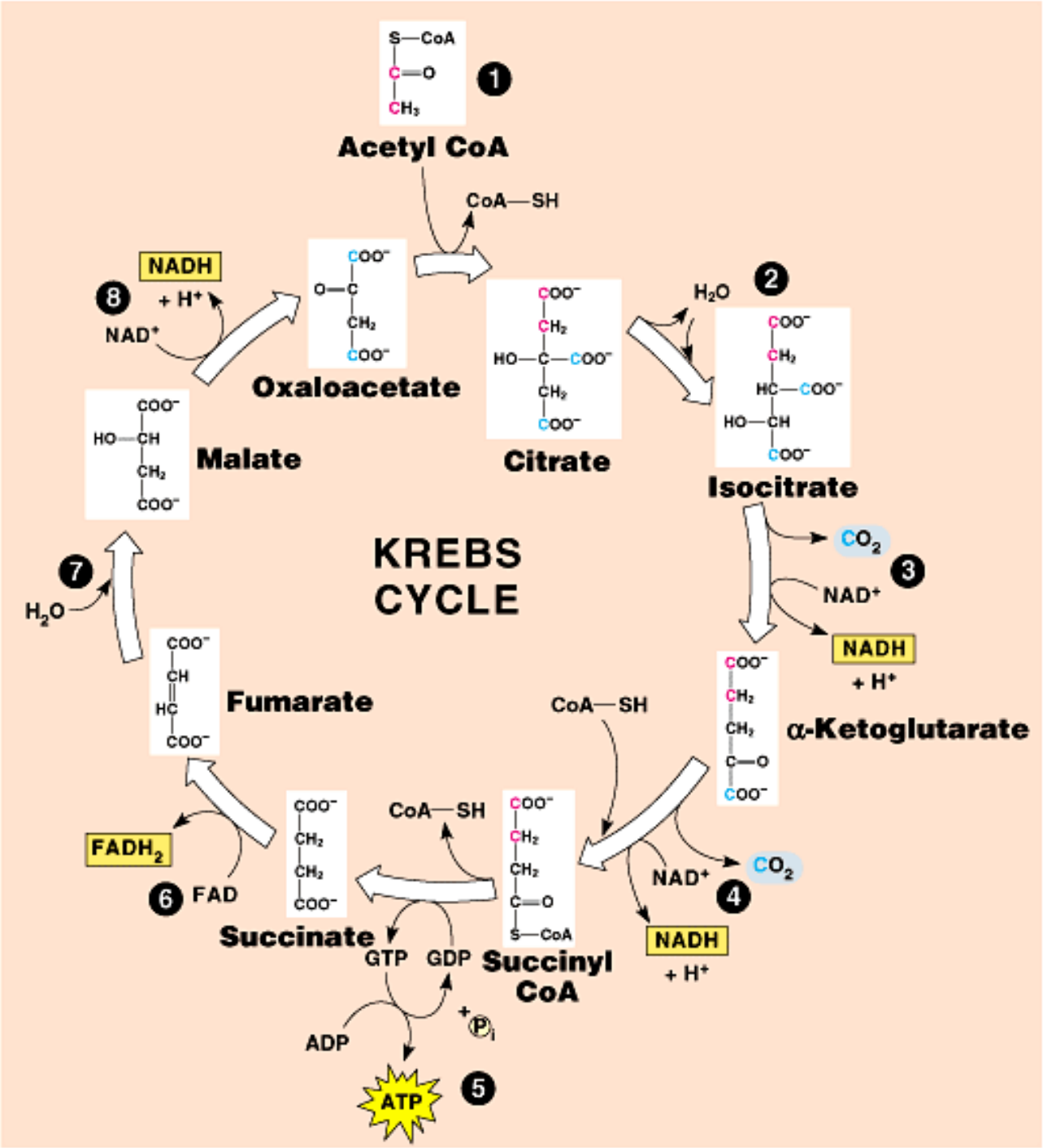
- <u>Mitochondrion anatomy review</u>
- Double membrane
  - Outer membrane
  - Inter-membrane space
- Inner membrane
  - Matrix
  - Cristae: folds of inner membrane



PYRUVATE

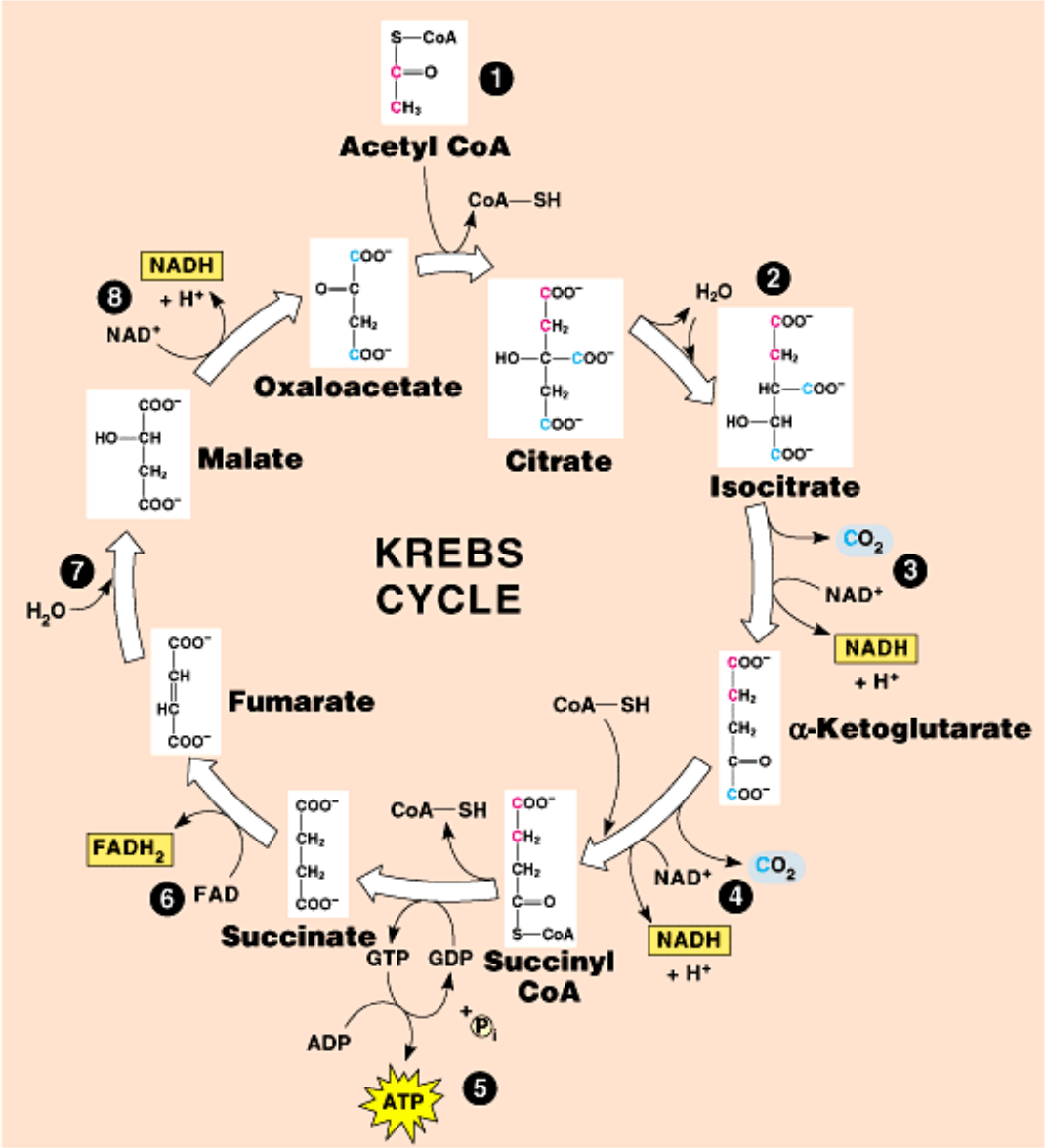
- Pyruvate is first modified to become Acetyl CoA
- CO_2 is released
- From there Acetyl CoA enters the Krebs Cycle




KREBS CYCLE
Acetyl CoA
CoA—SH
Citrate
H_2O
Isocitrate
CO_2
NAD^+
NADH
+ H^+
α-Ketoglutarate
CoA—SH
CO_2
NAD^+
NADH
+ H^+
Succinyl CoA
CoA—SH
Succinate
GTP
GDP
+ P_i
ADP
ATP
$FADH_2$
FAD
Fumarate
H_2O
Malate
NADH
+ H^+
NAD^+
Oxaloacetate

DOES THIS LOOK FAMILIAR?

- How is it similar to the Calvin Cycle?
- How is it different?

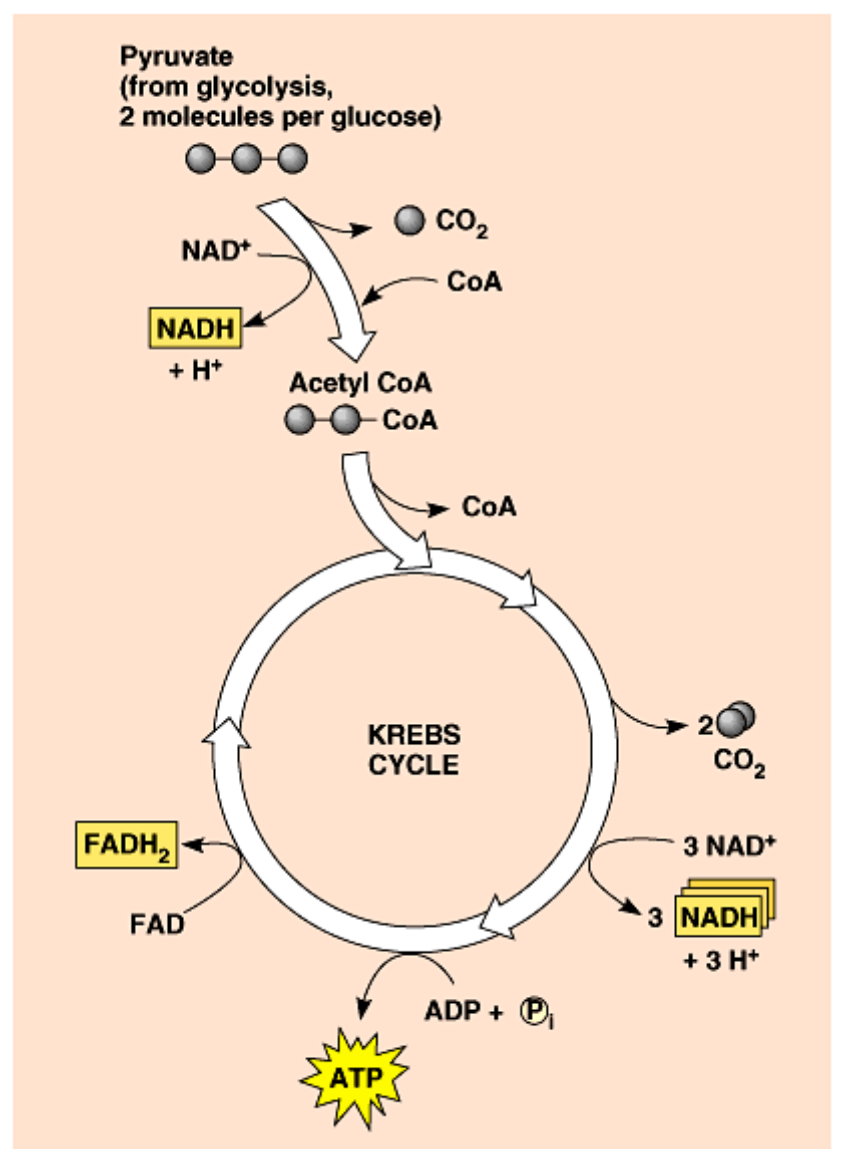


KREBS CYCLE (CITRIC ACID CYCLE)

- Basically, it is a series of reactions that release free energy, electrons and CO_2 from carbon-based molecules
- For each molecule of pyruvate:
  - Free energy is released and captured in 1 ATP molecule (substrate level phosphorylation)
  - Electrons are released and captured by 3 NADH and 1 $FADH_2$ molecules
  - 2 molecules of CO_2 are released

WELL, HOW DOES THIS FIT INTO OUR OVERALL GOAL?

- What is our goal?
- Making energy usable
- So how does it fit?



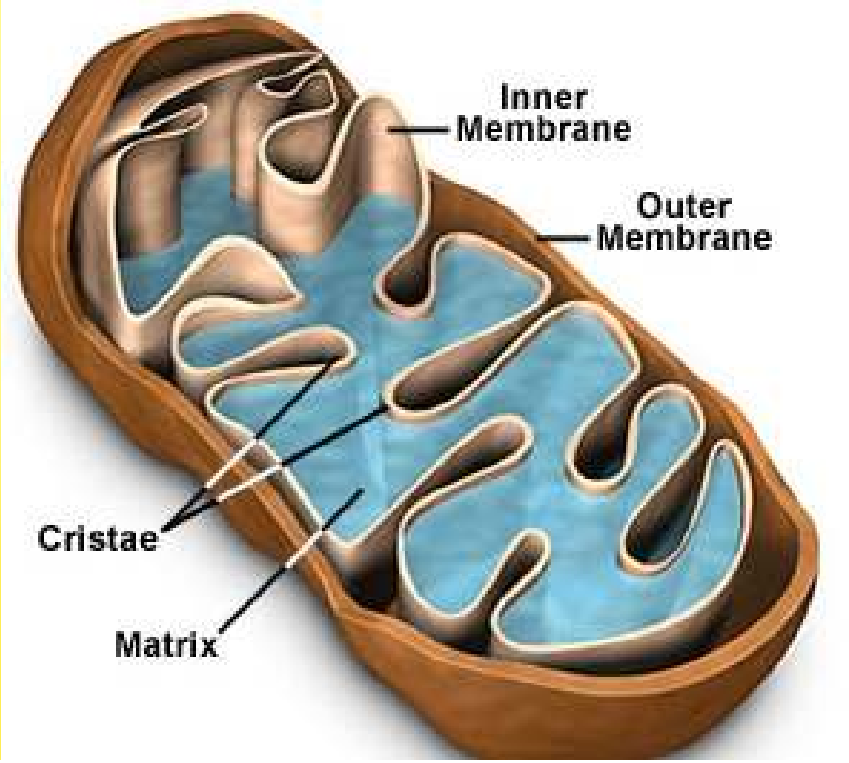
THERE HAS TO BE SOMETHING MORE!

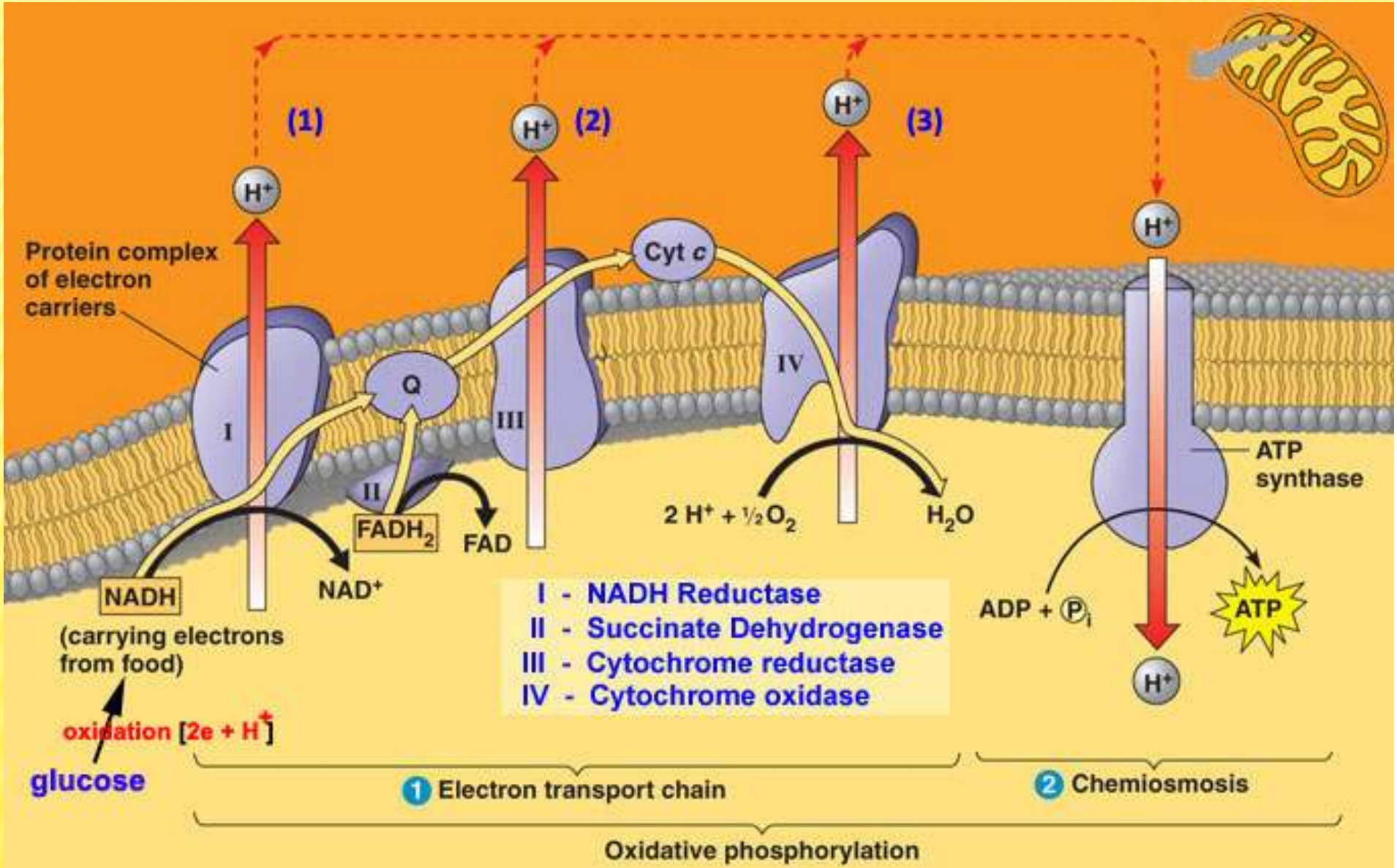
- Based on the products of the Krebs Cycle, what do you think happens next?

- Time for another Electron Transport Chain!

ELECTRON TRANSPORT CHAIN

- The electrons that were released in the Krebs cycle were captured by $FADH_2$ and NADH
- They travel from the matrix to the inner membrane
  - All other previously produced NADH also travels here



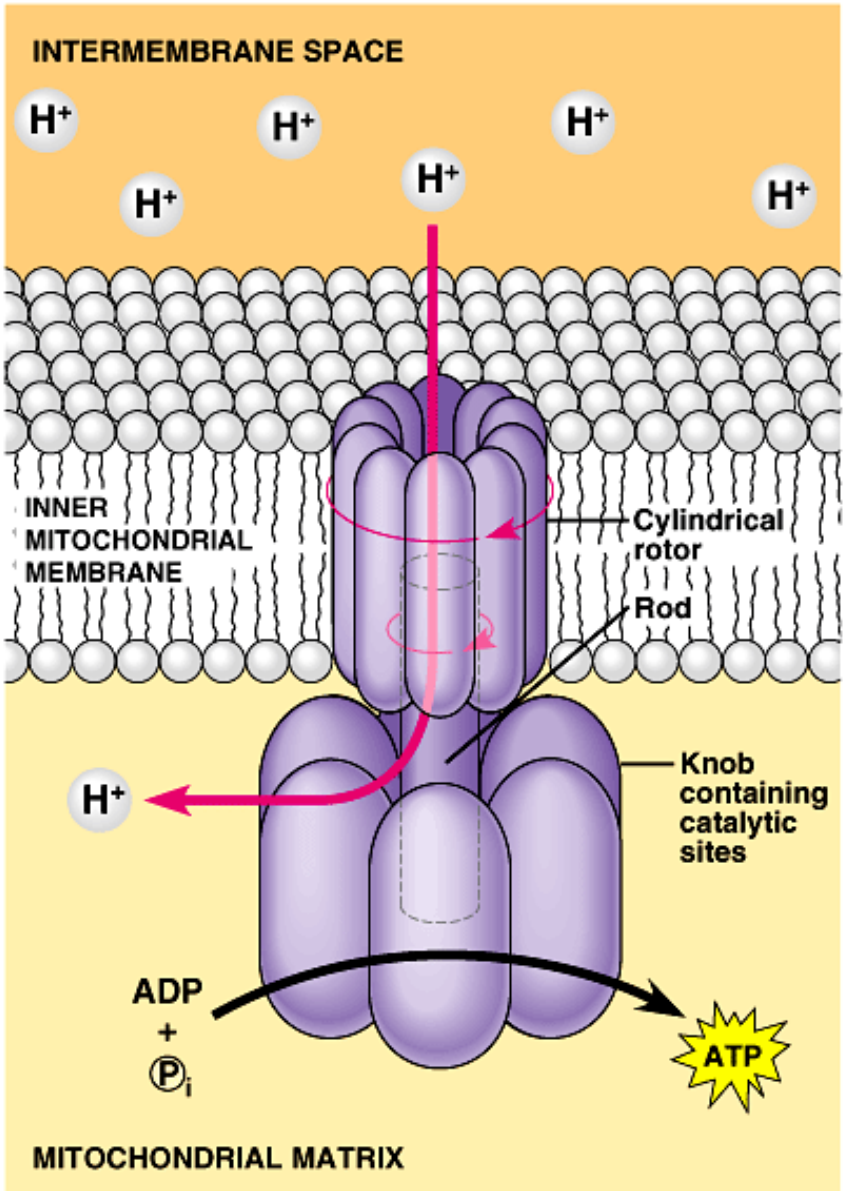

(1)
(2)
(3)
H+
Protein complex of electron carriers
Cyt c
I
II
III
IV
Q
FADH2
FAD
NADH
NAD+
(carrying electrons from food)
oxidation [2e + H+]
glucose
2 H+ + ½O2
H2O
ATP synthase
ADP + Pi
ATP
I - NADH Reductase
II - Succinate Dehydrogenase
III - Cytochrome reductase
IV - Cytochrome oxidase
1 Electron transport chain
2 Chemiosmosis
Oxidative phosphorylation

SIMILAR TO THE ETC IN PHOTOSYNTHESIS

- Electrons from $FADH_2$ and NADH are passed from one protein to the next through a series of oxidation/reduction reactions
- A concentration gradient is produced as protons (H^+) are transported from the matrix across the inner membrane and into the intermembrane space
  - Just like photosynthesis
- Electrons give away all of their free energy. After they are de-energized they are given to an oxygen molecule
  - Makes water with some protons
  - Oxidative phosphorylation

ATP SYNTHESIS

- Chemiosmosis occurs as protons pass through ATP synthase
- ATP is made from ADP and a phosphate



MISSION ACCOMPLISHED

- Free energy has been transferred from carbohydrates to ATP
  - Cellular Respiration produces roughly 36-38 ATP
  - ATP is a molecule that is useable by all cells
    - Free energy released for metabolic work!
    - ATP $\rightarrow$ ADP + P and then recycled
    - One working muscle cell can use (and recycle) 10 million ATP molecules every second

EQUATION FOR RESPIRATION

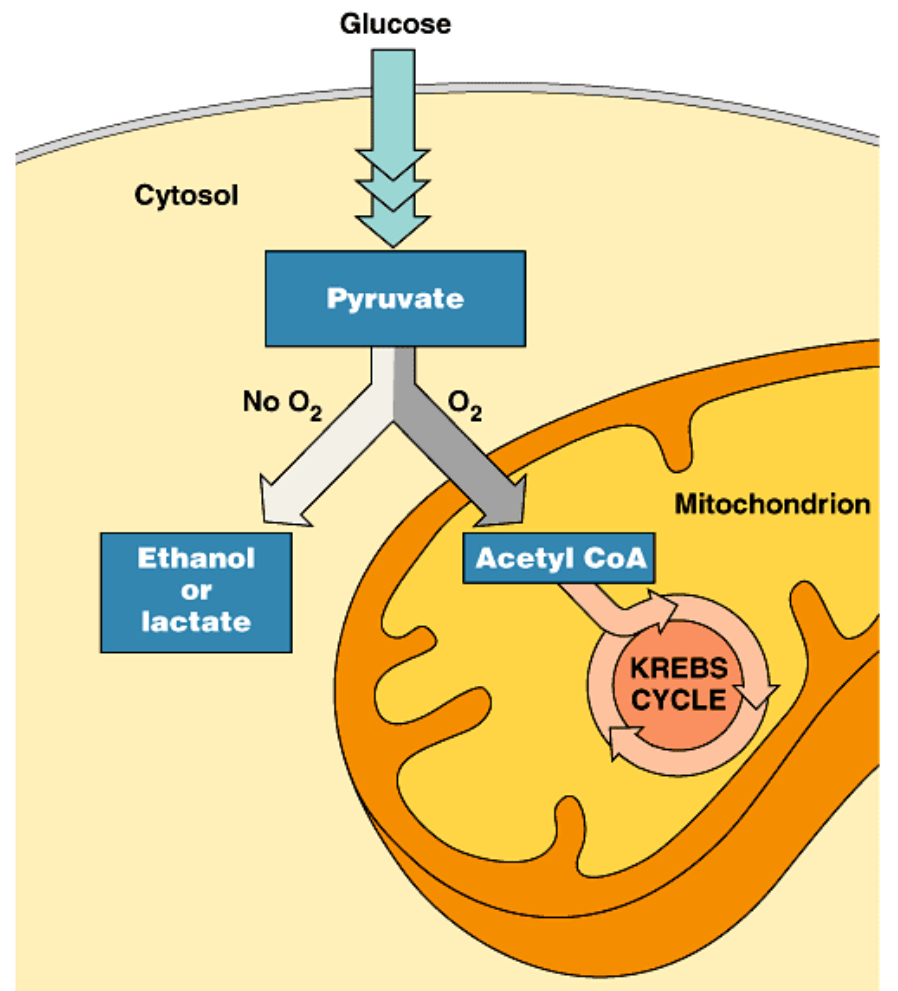
COMPARING PHOTOSYNTHESIS AND RESPIRATION

- $6\ CO_2 + 6\ H_2O + \text{Light energy} \rightarrow C_6H_{12}O_6 + 6\ O_2$

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

TIME FOR FERMENTATION

- Why might fermentation be a beneficial process?



FERMENTATION

- Obligate aerobes and obligate anaerobes
  - Bacillus and Clostridium
- Facultative anaerobes
  - Yeast, bacteria and us!

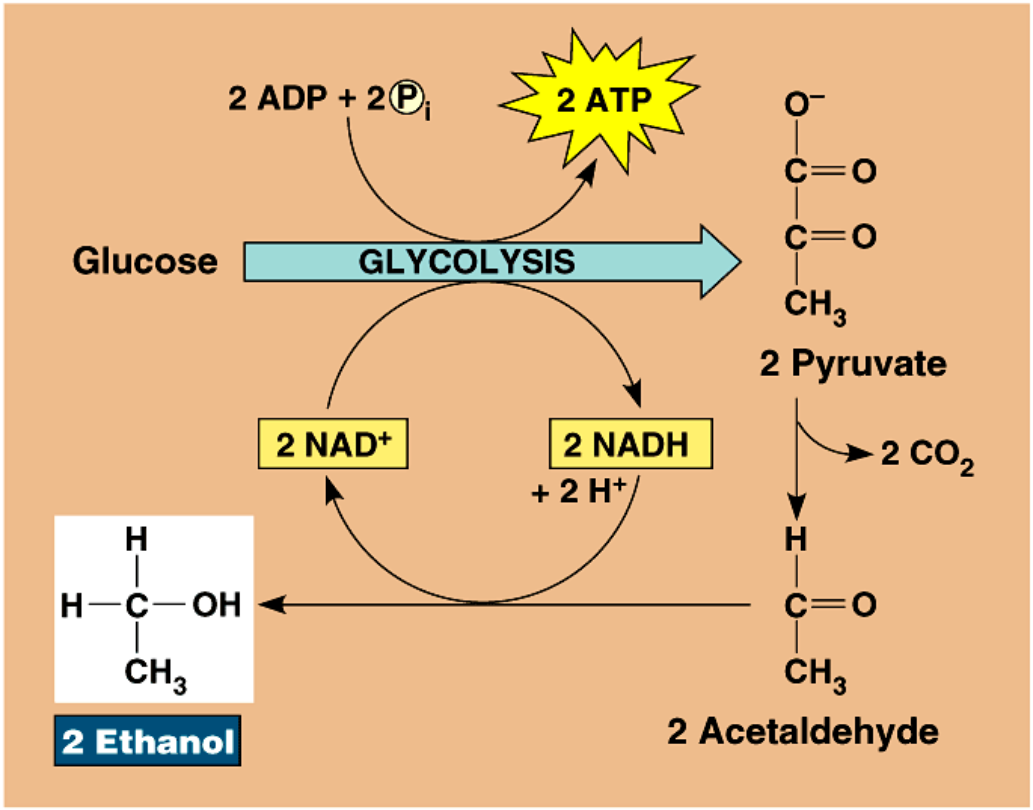
TWO TYPES OF FERMENTATION

- Alcohol fermentation
- Lactic Acid fermentation

- Both types named for the byproduct
- Each process produces ATP
  - Not as productive (# of ATP) as cellular respiration!!

Alcohol Fermentation

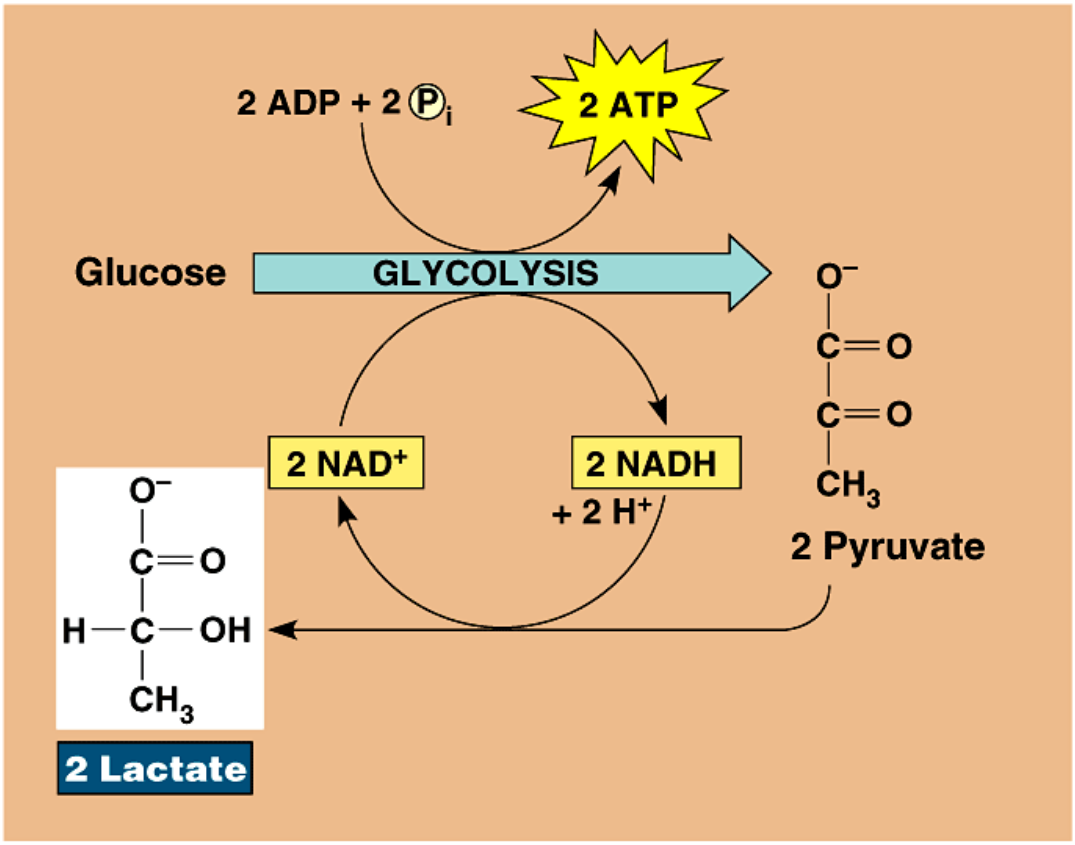
- NADH (from glycolysis) converts pyruvate into ethanol and CO_2
- Yeast
  - CO_2 makes bread rise
  - Ethanol for alcohols



(a) Alcohol fermentation

Lactic Acid Fermentation

- NADH (from glycolysis) converts pyruvate into lactate
- No CO_2 release



(b) Lactic acid fermentation

Lactic Acid Fermentation

- Used to make delicious cheese and yogurt
- Muscle cells make lactic acid when ATP production moves faster than O_2 intake
  - Lactic acid contributes to soreness and fatigue- later converted back to pyruvate

AN APPLICATION

- Thermoregulation- decouples oxidative phosphorylation from electron transport
- Heat is made and ATP is not produced
- Helps warm an animal up