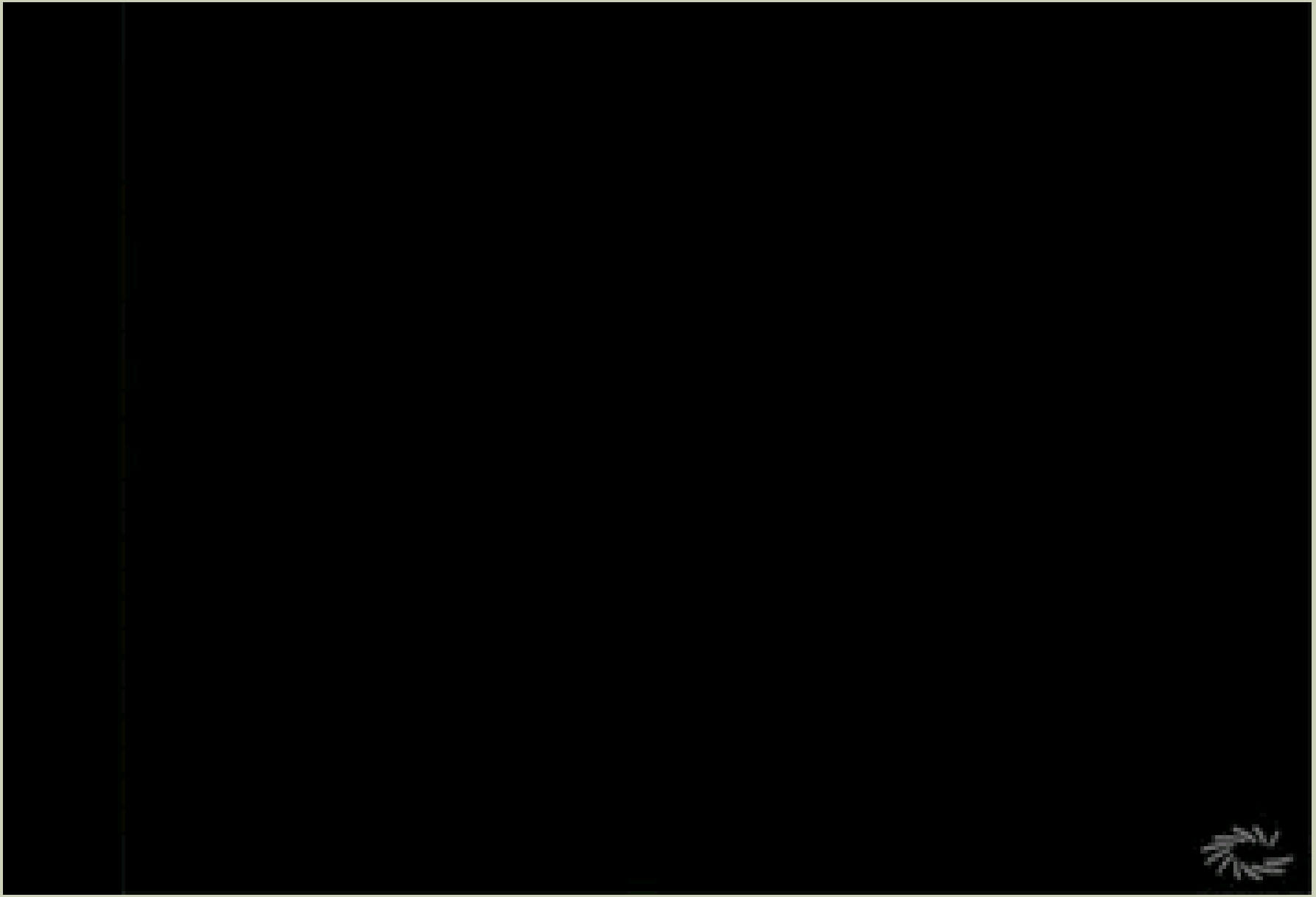
CELLULAR RESPIRATION

GETTING ENERGY TO MAKE ATP



CELLULAR RESPIRATION

- Cellular process by which mitochondria **releases** **energy** by breaking down food molecules (**glucose** or other organic molecules) to produce energy **(ATP)**

- ***Mitochondria*** → powerhouse of cell; organelle that "transfers" the energy – ***location of Cellular Respiration***

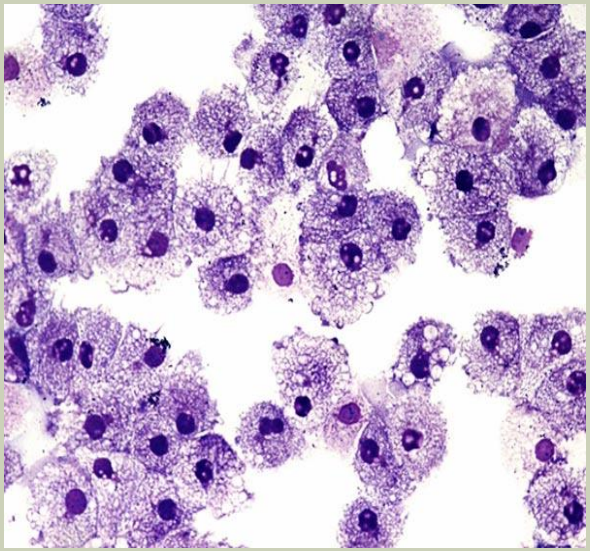
- *OPPOSITE OF PHOTOSYNTHESIS

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O \ (\text{ATP})$$

glucose

CELLULAR RESPIRATION

- What "respires?"
  - Plants and Animals
  - ALL living organisms!



BACKGROUND INFO..

-lots of chemical reactions -controlled by enzymes

Important patterns:

*energy released -> captured by ADP to make ATP

*energized H released ->captured by NAD to make NADH & H^+ or captured by FAD to make $FADH_2$

NAD is like catcher's mitt– catches fastball/high energy H

FAD is like fielder's mitt – catches slower ball/lower energy H

*when C atom is lost, it is released as CO_2

AEROBIC RESPIRATION

Respiration in the presence of free oxygen, resulting in the complete oxidation of glucose to carbon dioxide and water as well as the release of a net of 36 ATP's.

CELLULAR RESPIRATION

- 4 STAGES (reactions) →
  - 1. Glycolysis (splitting of glucose)
    - cytoplasm, just outside of mitochondria
  - 2. Pyruvic Acid breakdown
    - migration from cytoplasm to mitochondria
  - 3. Citric Acid Cycle/Krebs Cycle
    - mitochondria
  - 4. Electron Transport Chain
    - mitochondria

1. GLYCOLYSIS
"SPLITTING OF GLUCOSE"

- Location → Cytoplasm (outside of mitochondria)
- 2 phases: energy investment phase (2 ATP activation energy) AND energy yielding phase (4 ATP produced)
- Breaks down:

6-C compound (Glucose)

↓

2, 3-C compounds (2 pyruvic acid)

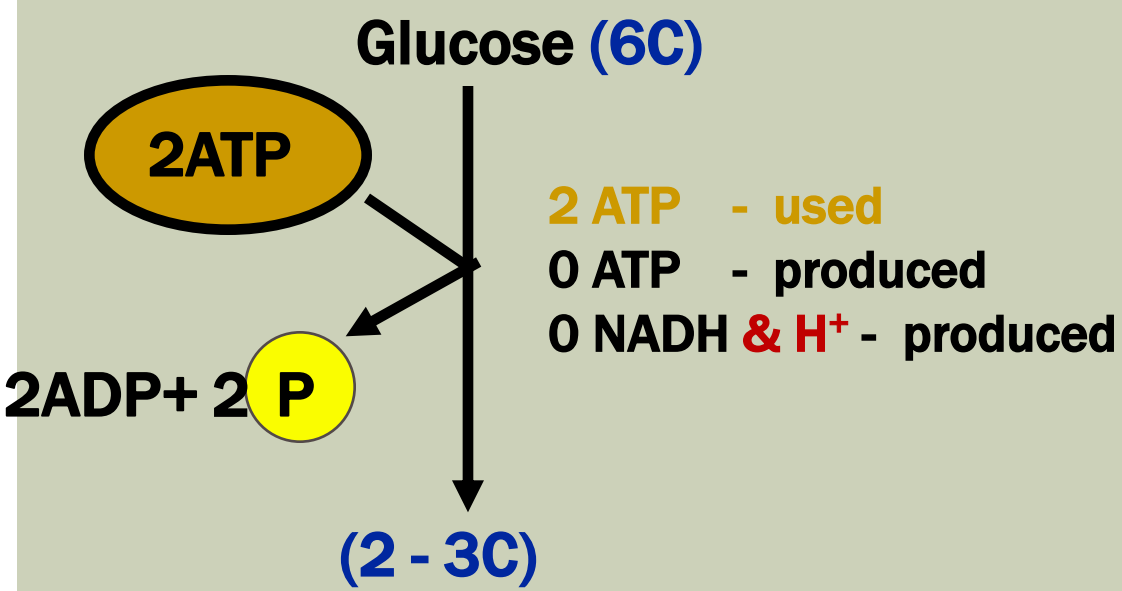
↓

moves from cytoplasm to mitochondria

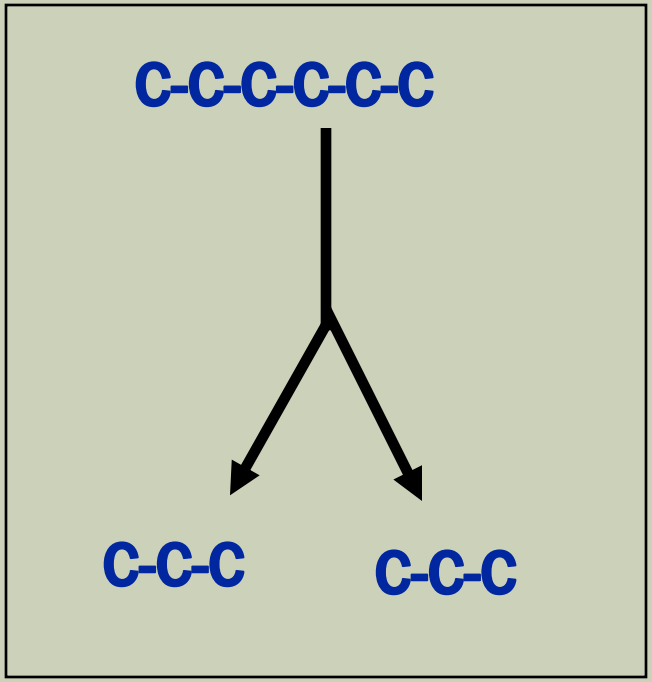
- Needs 2 ATP to start
- Makes 4 ATP, so profits 2 ATP

1. GLYCOLYSIS

A. Energy Investment Phase:



2 ATP - used
0 ATP - produced
0 NADH & H^+ - produced



1. GLYCOLYSIS

B. Energy Yielding Phase

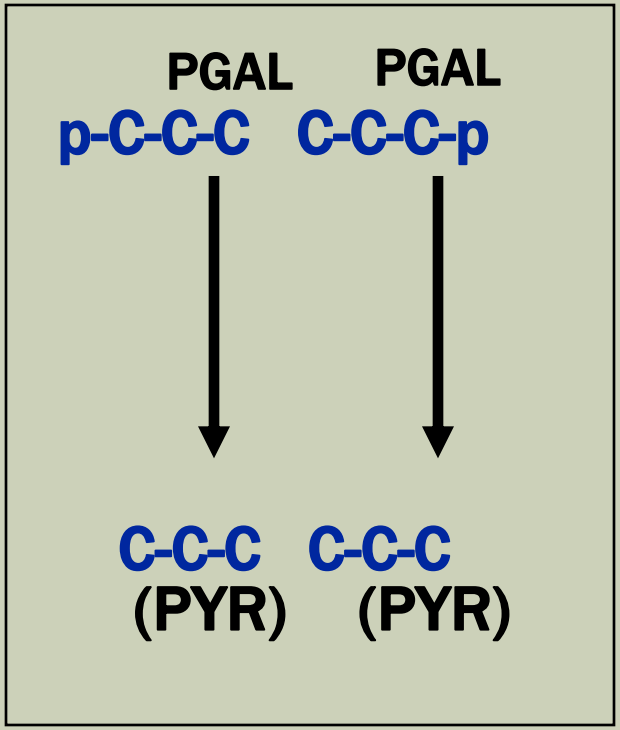
(2 - 3C)

4ADP+4 P

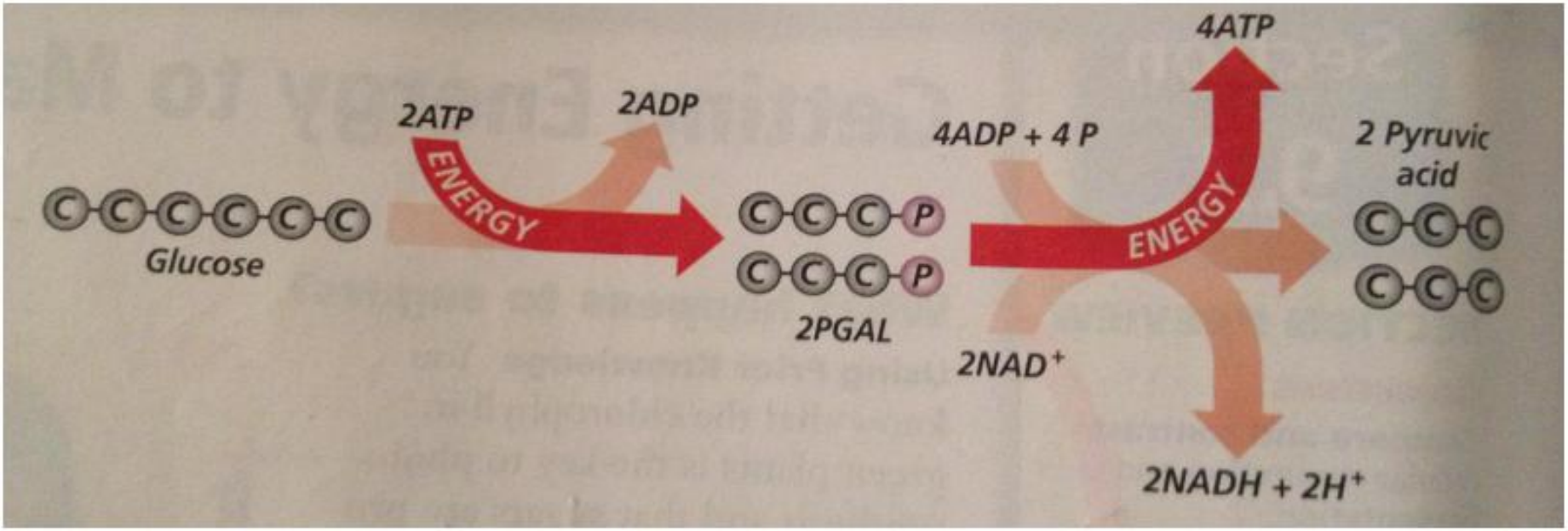
4ATP

0 ATP - used
4 ATP - produced
2 NADH & H^+ - produced

Pyruvate (2 - 3C)
or Pyruvic Acid (PYR)



1. GLYCOLYSIS
"SPLITTING OF GLUCOSE"



Total Net Yield

2 - 3C-Pyruvic acid (Pyruvate)

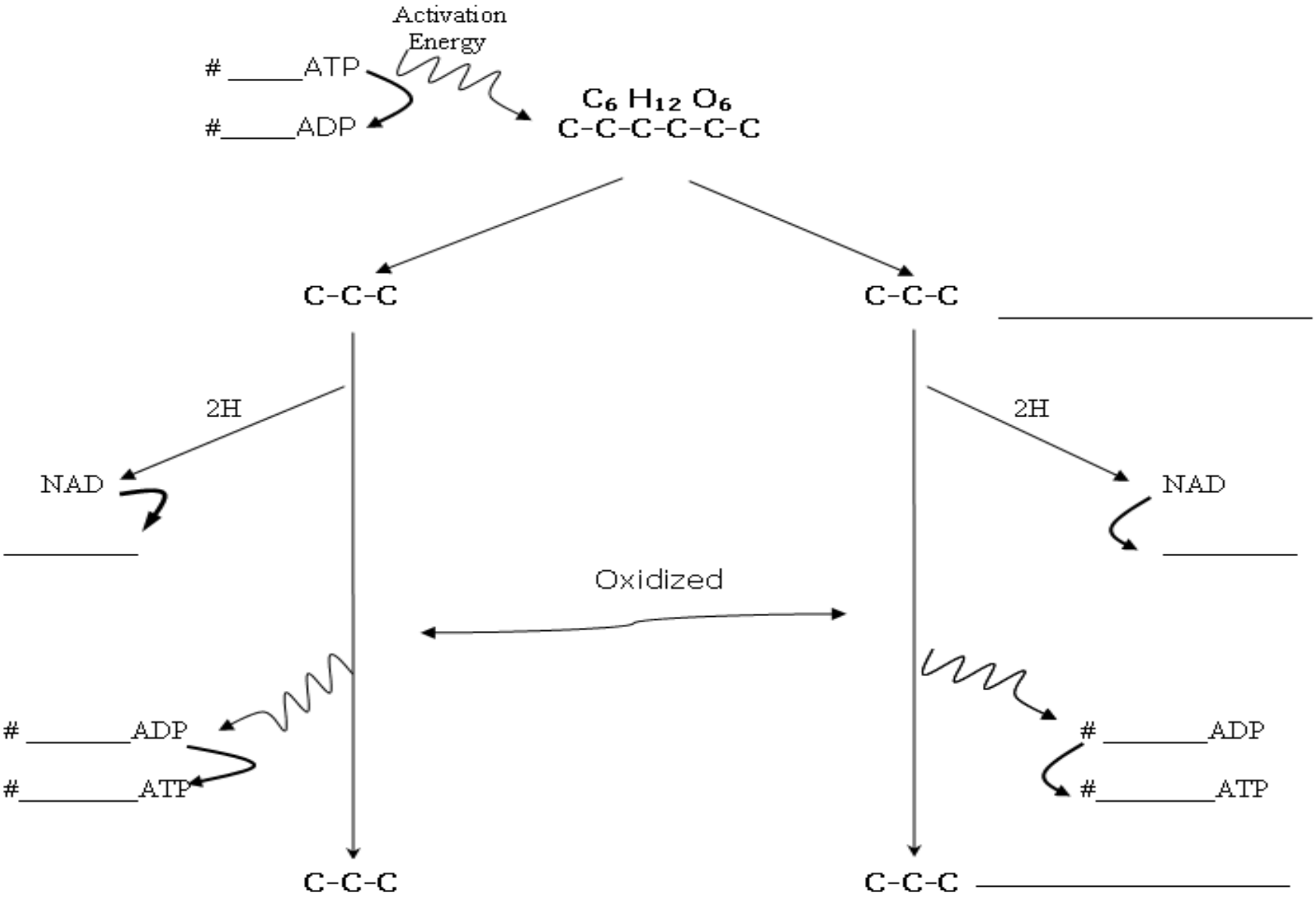
2 – ATP (Stored Chemical Energy)

(4 ATP produced-2 used as Activation Energy)

2 – NADH (will turn into ATP later on)

1. GLYCOLYSIS

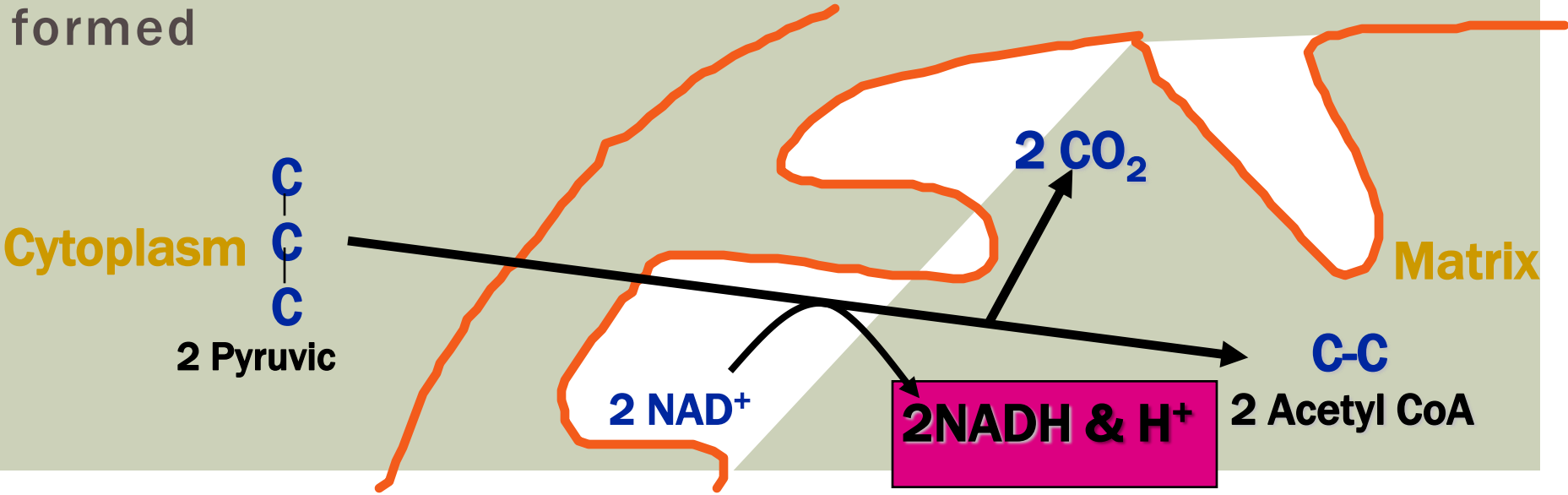
- If Oxygen is present, goes on to Citric Acid Cycle (& then E.T.C.)
- For this to happen, 2 pyruvic acid (3C) undergoes series of reactions and carbon dioxide is given off – transported via mitochondria
- Combines with coenzyme A → (2) Acetyl coA molecules formed


Activation Energy
_____ATP
#_____ADP
C6 H12 O6
C-C-C-C-C-C
C-C-C
C-C-C
2H
NAD
2H
NAD
Oxidized
_____ADP
#_____ATP
_____ADP
#_____ATP
C-C-C
C-C-C

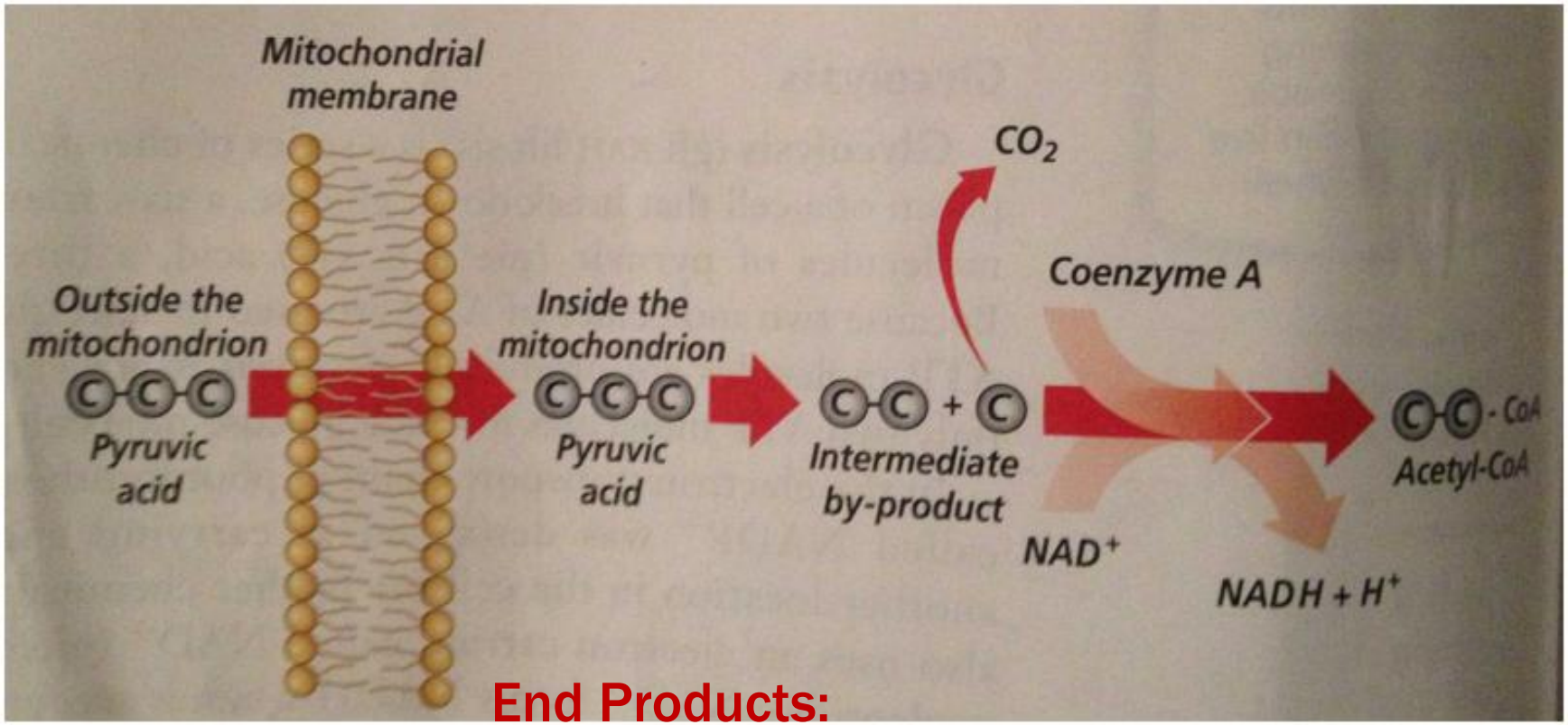
GLYCOLYSIS

2. PYRUVIC ACID BREAKDOWN

- If Oxygen is present (aerobic), goes on to Citric Acid Cycle (& then E.T.C.)
- For this to happen, 2 pyruvic acid (3C) undergoes series of reactions and carbon dioxide is given off – transported via mitochondria
- Combines with coenzyme A → (2) Acetyl coA molecules formed

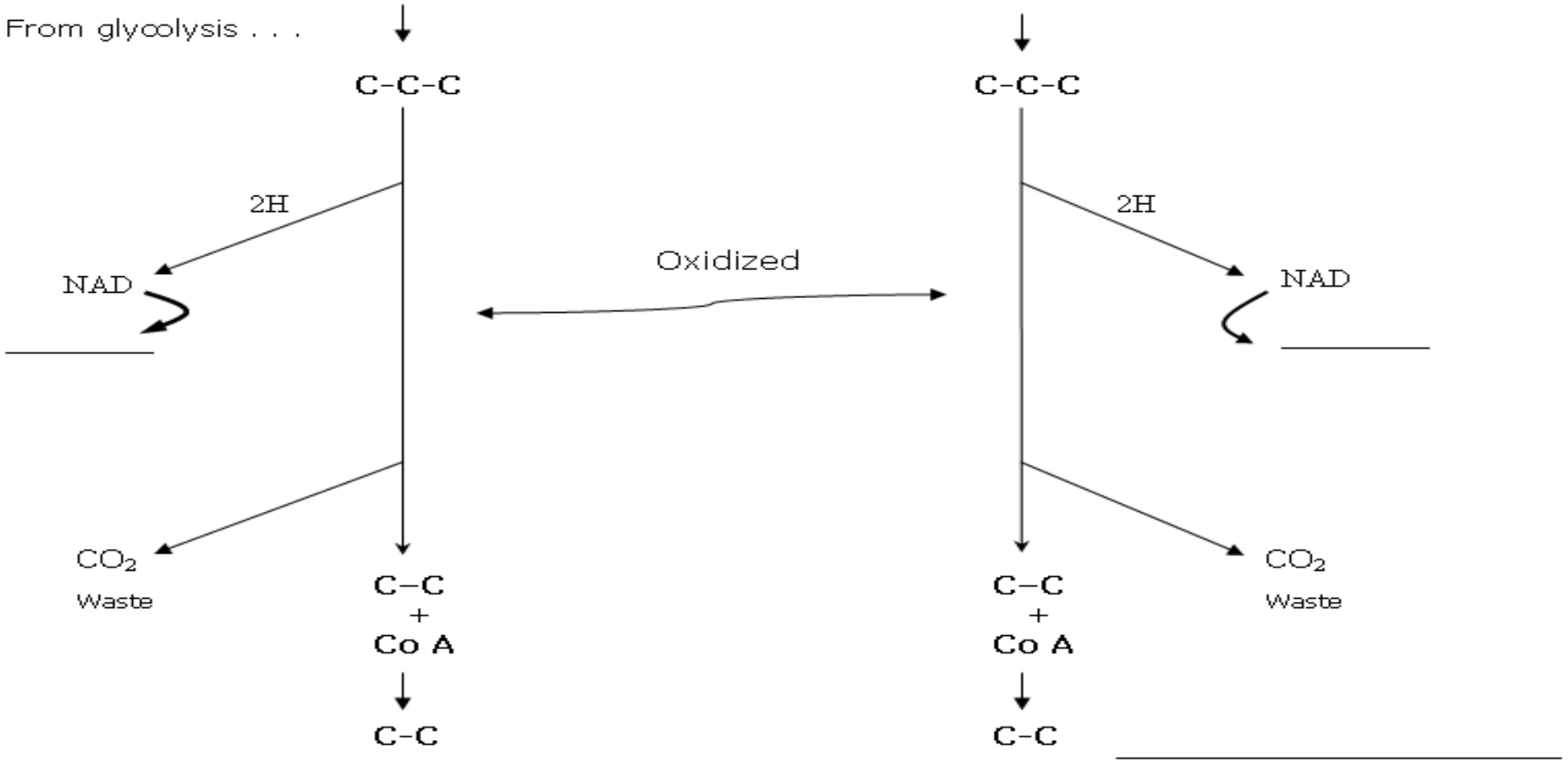


GLYCOLYSIS…TO CITRIC ACID CYCLE & E.T.C



End Products:

- 2 – NADH (will turn into ATP later on)
- 2 - CO_2 (Released as waste)
- 2 - Acetyl CoA (2C)
  - *Enters Kreb Cycle



Pyruvic Acid Breakdown

3. CITRIC ACID CYCLE

- AKA: Kreb's Cycle
- Location: Mitochondria
- Breaks down (2 molecules of) acetyl-coA, forming → Citric acid (6C), ATP, & CO_2
- Similar to Calvin Cycle
  - Molecule used in 1st reaction is also one of its end products

3. CITRIC ACID CYCLE/KREB'S CYCLE

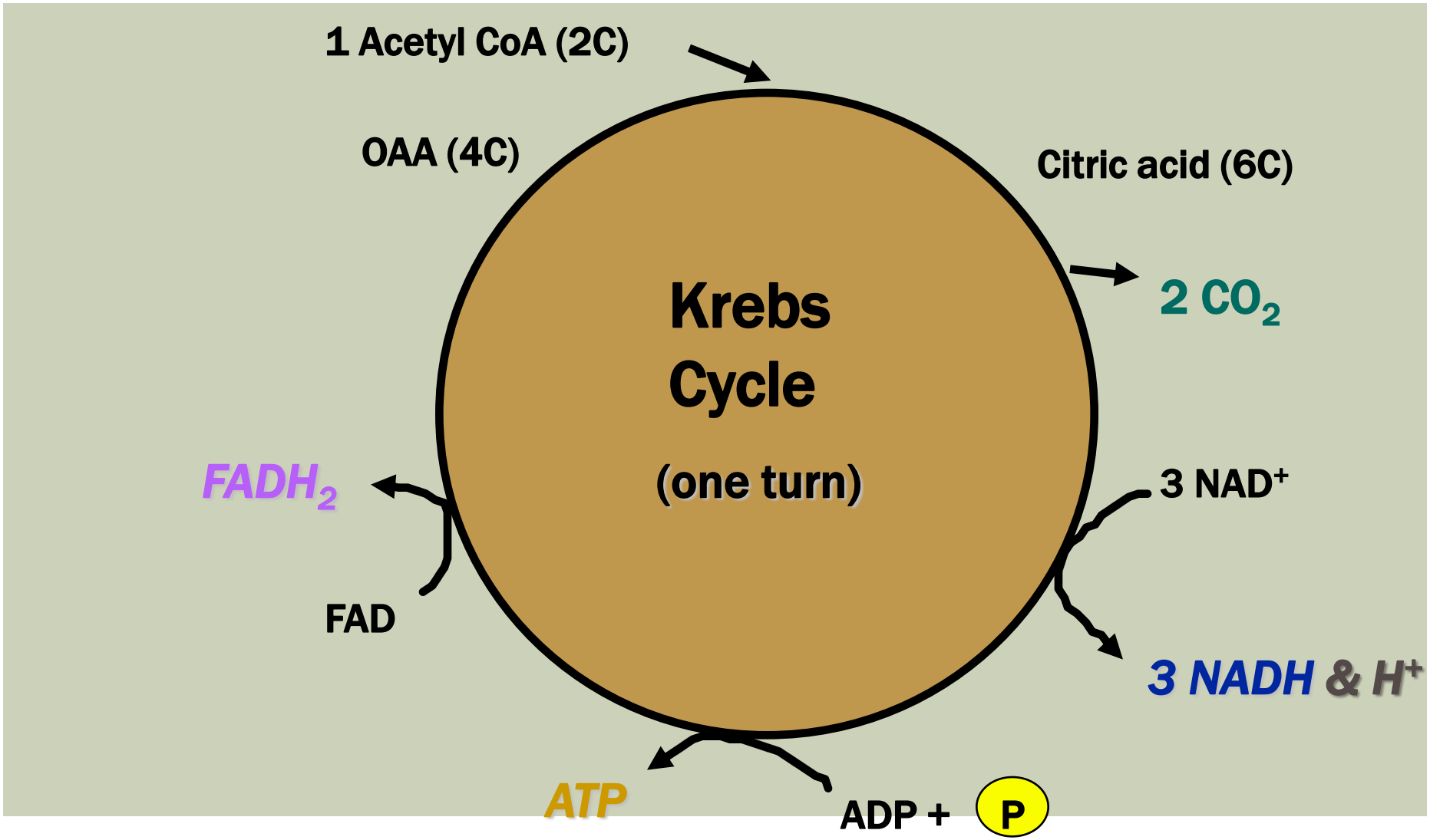
- Goes through 2 turns of the cycle
  - Because there are 2 Acetyl-coA molecules
  - Takes 2 turned of krebs cycle to oxidize 1 glucose molecule
- Every turn of cycle produces →
  - 1 ATP Molecule
  - 2 CO_2 Molecules
- Electron carriers used → NAD+, FAD+
- Each electron carrier passes 2 energized electrons along to E.T.C.

3. KREBS CYCLE (CITRIC ACID CYCLE)

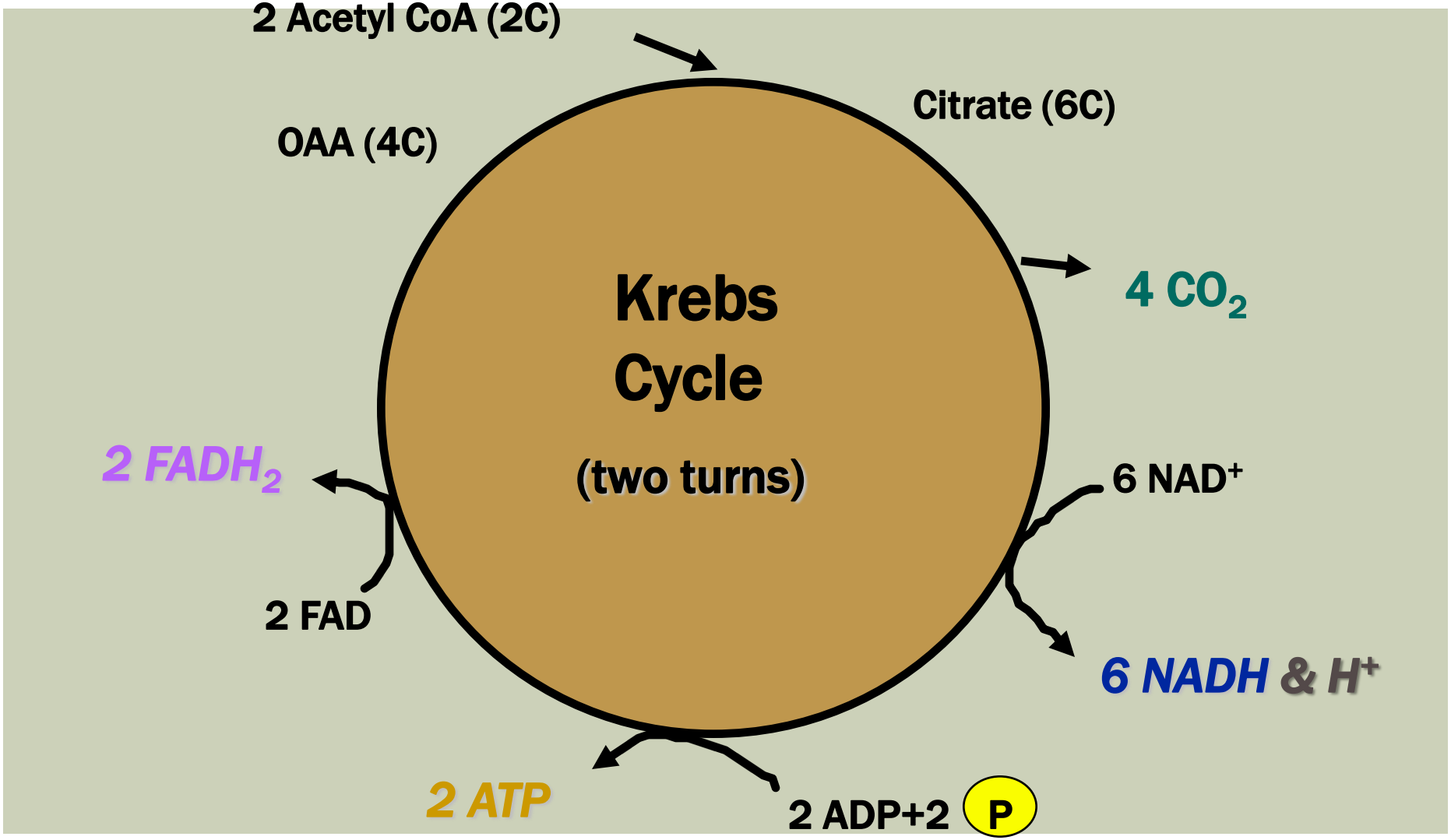
- **Total net yield (2 turns of krebs cycle)**

1. **2 - ATP**
2. **6 – NADH & H^+**
3. **2 - $FADH_2$**
4. **4 - CO_2**

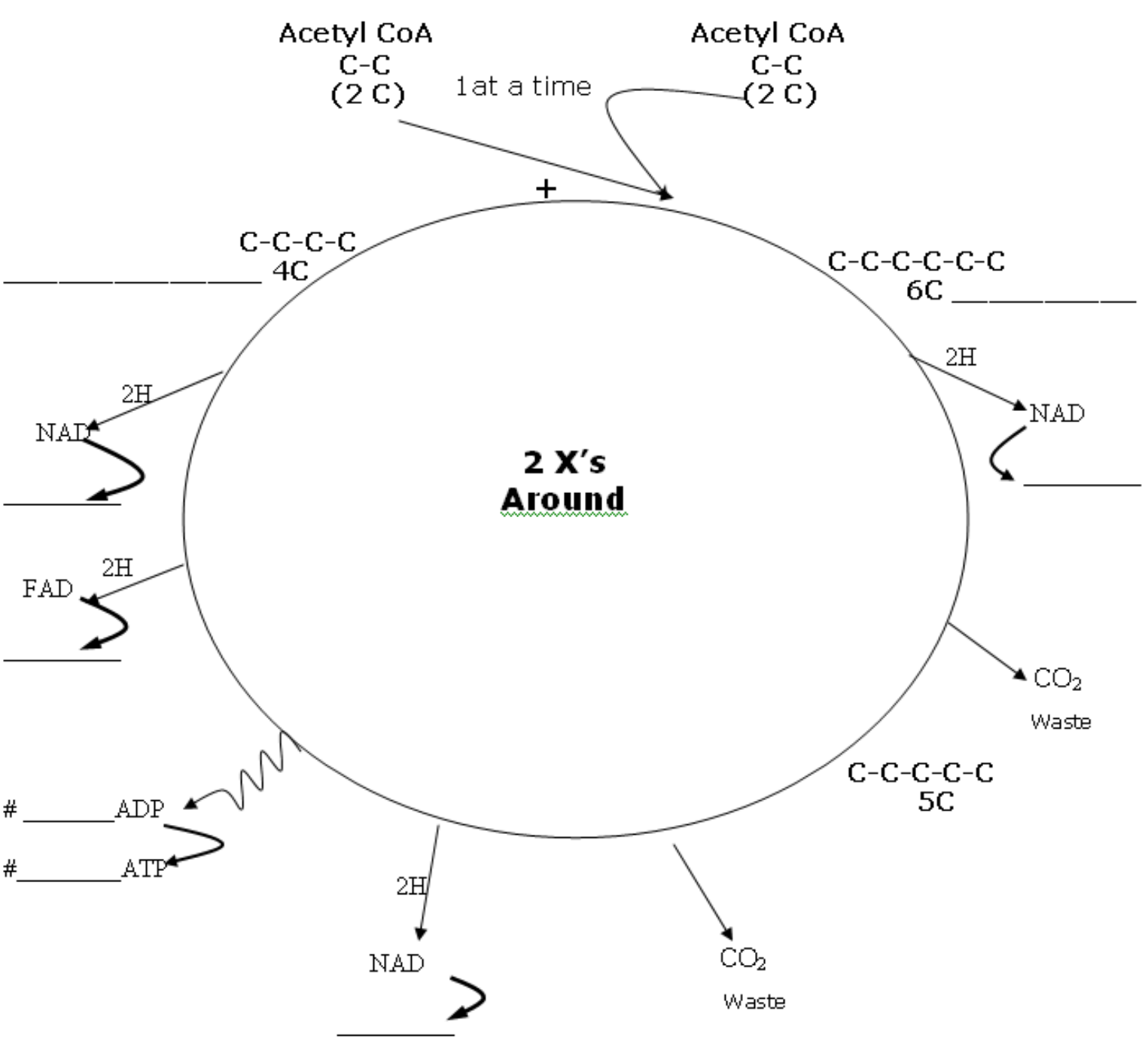
3. KREBS CYCLE (CITRIC ACID CYCLE)



3. KREBS CYCLE (CITRIC ACID CYCLE)



Krebs Cycle


Acetyl CoA
C-C
(2 C)
1at a time
Acetyl CoA
C-C
(2 C)
+
C-C-C-C
4C
C-C-C-C-C-C
6C
2H
NAD
2H
NAD
2 X's
Around
2H
FAD
CO_2
Waste
C-C-C-C-C
5C
ADP
ATP
2H
NAD
CO_2
Waste

4. ELECTRON TRANSPORT CHAIN

- Location: inner membrane of mitochondria
- (similar to E.T.C. in photosynthesis)

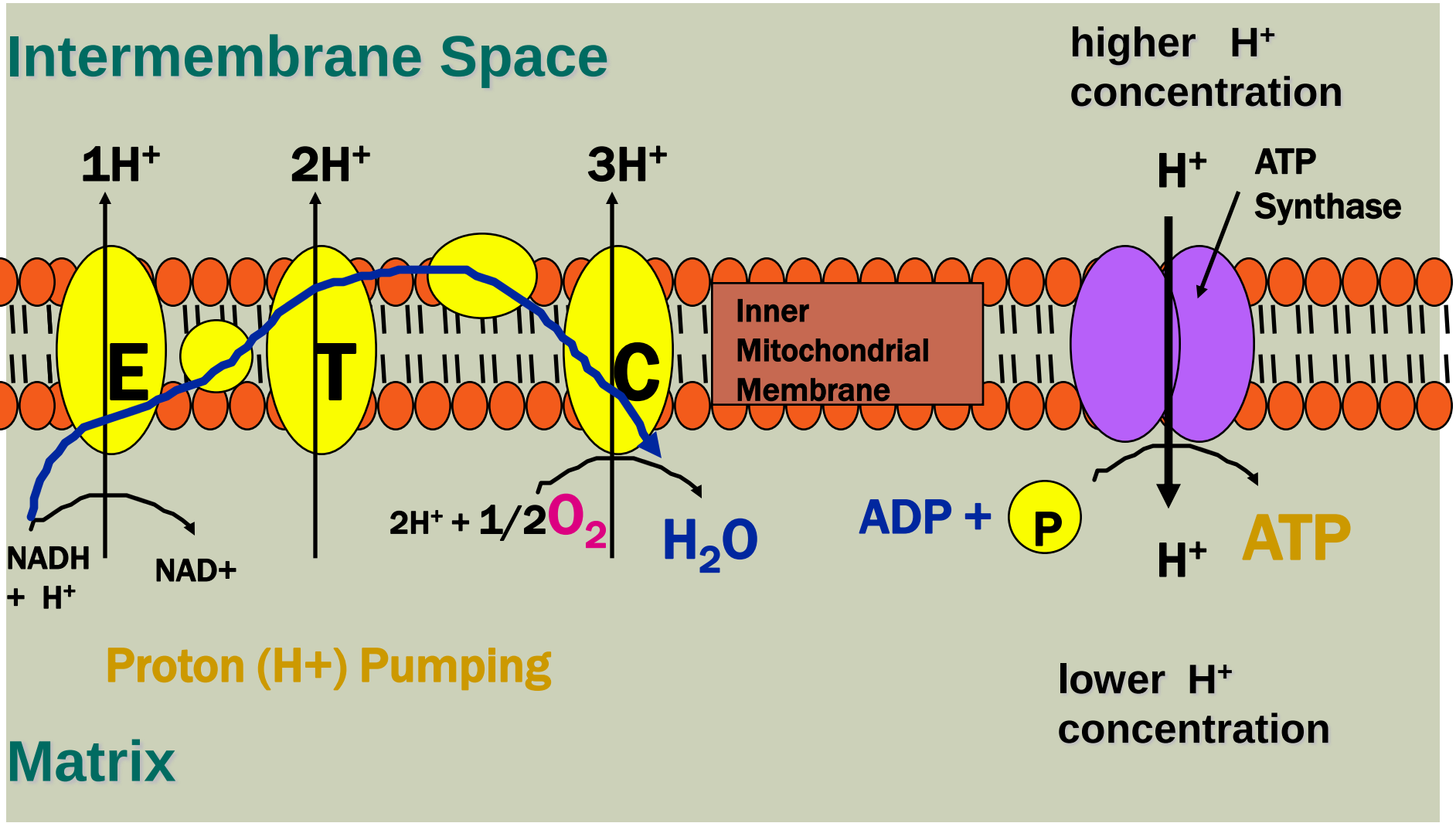
- NADH & FADH2 (from Kreb's Cycle) deliver energized electrons
  - Each **NADH** converts to **3 ATP**.
  - Each **$FADH_2$** converts to **2 ATP**

- Electrons are passed from protein to protein and energy is released

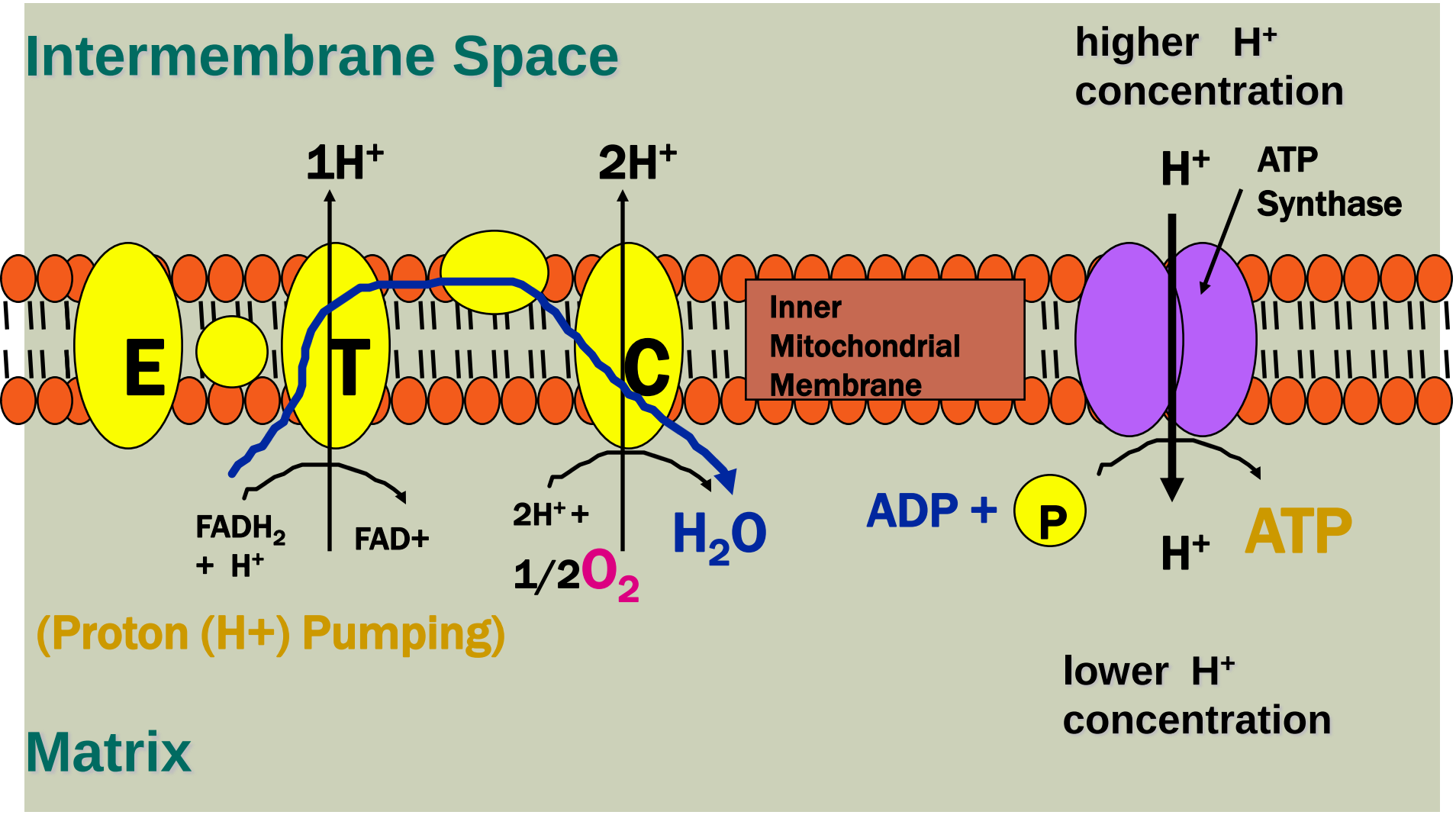
ELECTRON TRANSPORT CHAIN

- Some energy used to make ATP
- Other energy used by an enzyme → (ATP synthase) pumps Hydrogen ions into center of mitochondria
- Sets up concentration gradient: diffuses hydrogen ions to provide energy (as needed) to continue to produce ATP (from ADP)

4. ETC AND CHEMIOSMOSIS FOR NADH

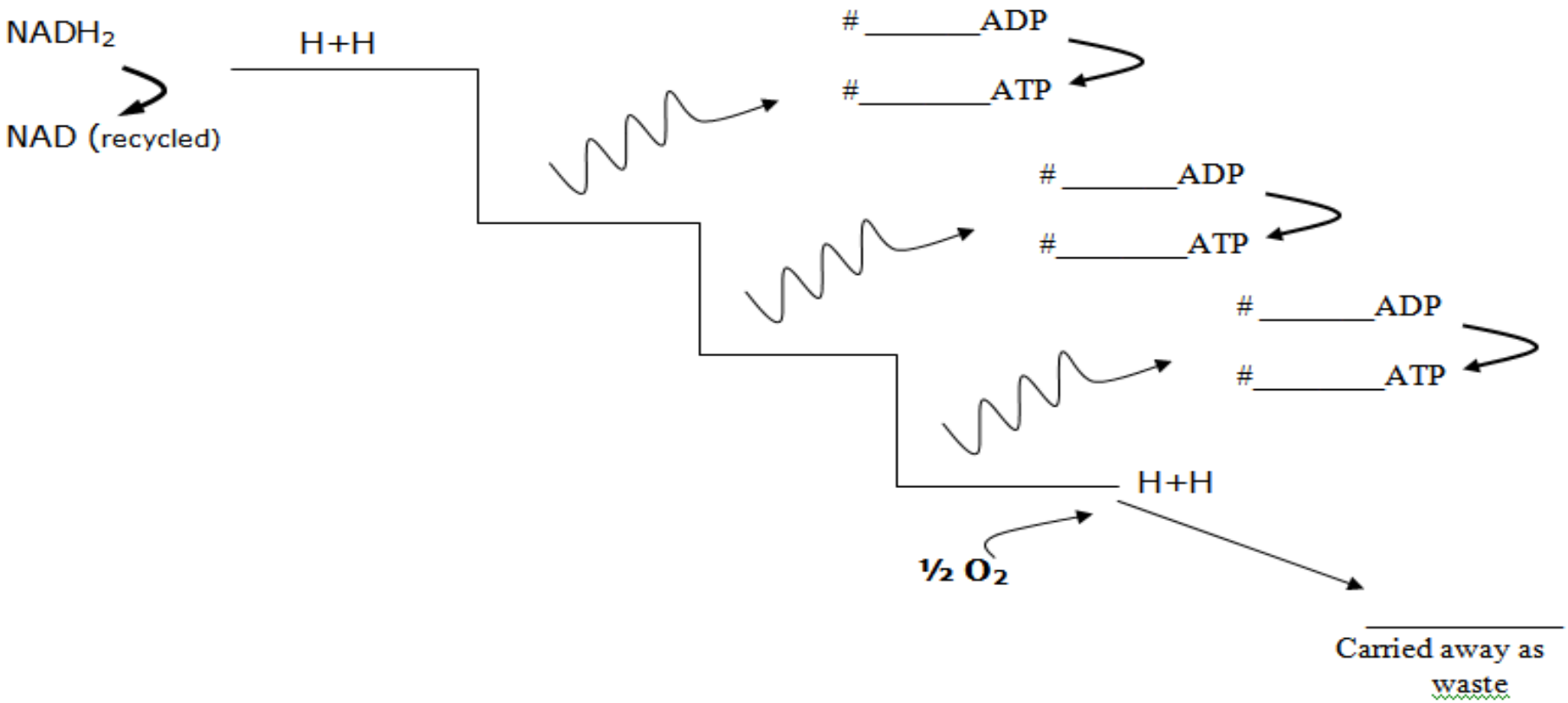


4. ETC AND CHEMIOSMOSIS FOR $\underline{FADH_2}$



ELECTRON TRANSPORT CHAIN

- Final electron acceptor = oxygen
- Reacts with 4 hydrogen ions and 4 electrons → forms 2 water (H20) molecules



Electron

Transport

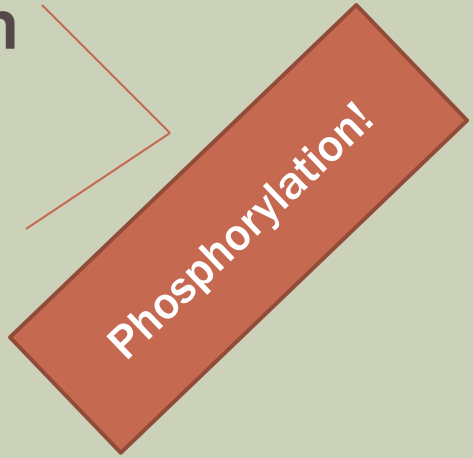
Chain

ELECTRON TRANSPORT CHAIN

- Without oxygen, proteins in E.T.C. can<u>not</u> pass along the electrons
- If cannot pass them, cannot accept another electron
- So chain would be blocked and ATP production would stop
- This is why it's called AEROBIC! (requires oxygen to occur)

COUNT 'EM UP

- ATP MOLECULES MADE →
  - E.T.C. = 34 ATP
  - Kreb's Cycle = 2 ATP (1 ATP from each cycle)
  - Glycolysis = 2 ATP



- TOTAL = 38 ATP
- So, very effective <u>with</u> oxygen

EUKARYOTES (HAVE MEMBRANES)

Remember:
1 NADH = 3 ATP
1 $FADH_2$ = 2 ATP

- Total ATP Yield

02 ATP - glycolysis (substrate-level phosphorylation)

04* ATP - converted from 2 NADH – glycolysis

06 ATP - converted from 2 NADH – pyruvic acid breakdown phase

02 ATP - Krebs cycle (substrate-level phosphorylation)

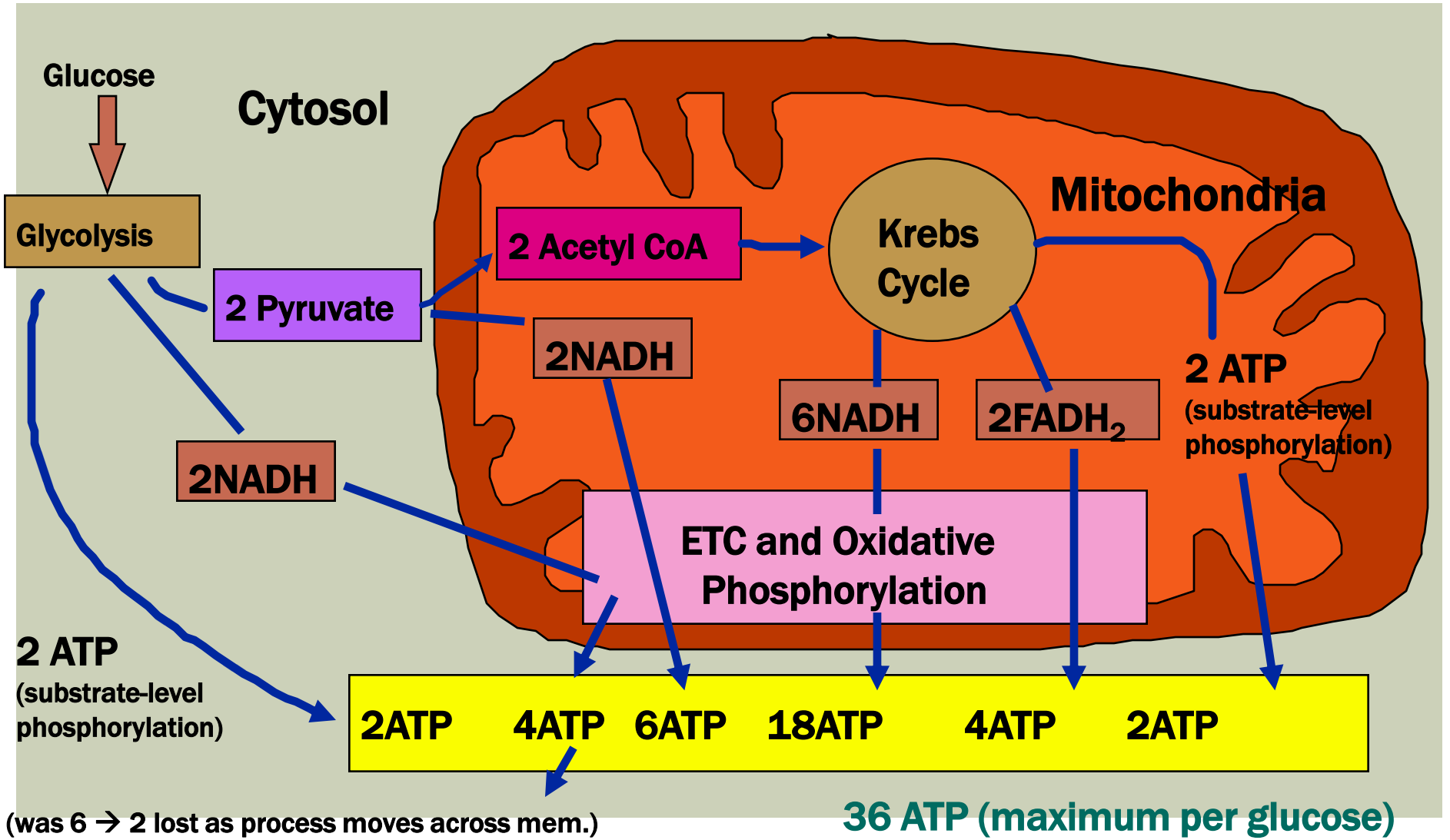
18 ATP - converted from 6 NADH - Krebs cycle

04 ATP - converted from 2 $FADH_2$ - Krebs cycle

36 ATP - TOTAL

**** = 2 less due to having a membrane → lose 2 to get across mitochondrial membrane***

MAXIMUM ATP YIELD FOR CELLULAR RESPIRATION (EUKARYOTES)



PROKARYOTES (LACK MEMBRANES)

- Total ATP Yield

02 ATP - glycolysis (substrate-level phosphorylation)

06 ATP - converted from 2 NADH - glycolysis

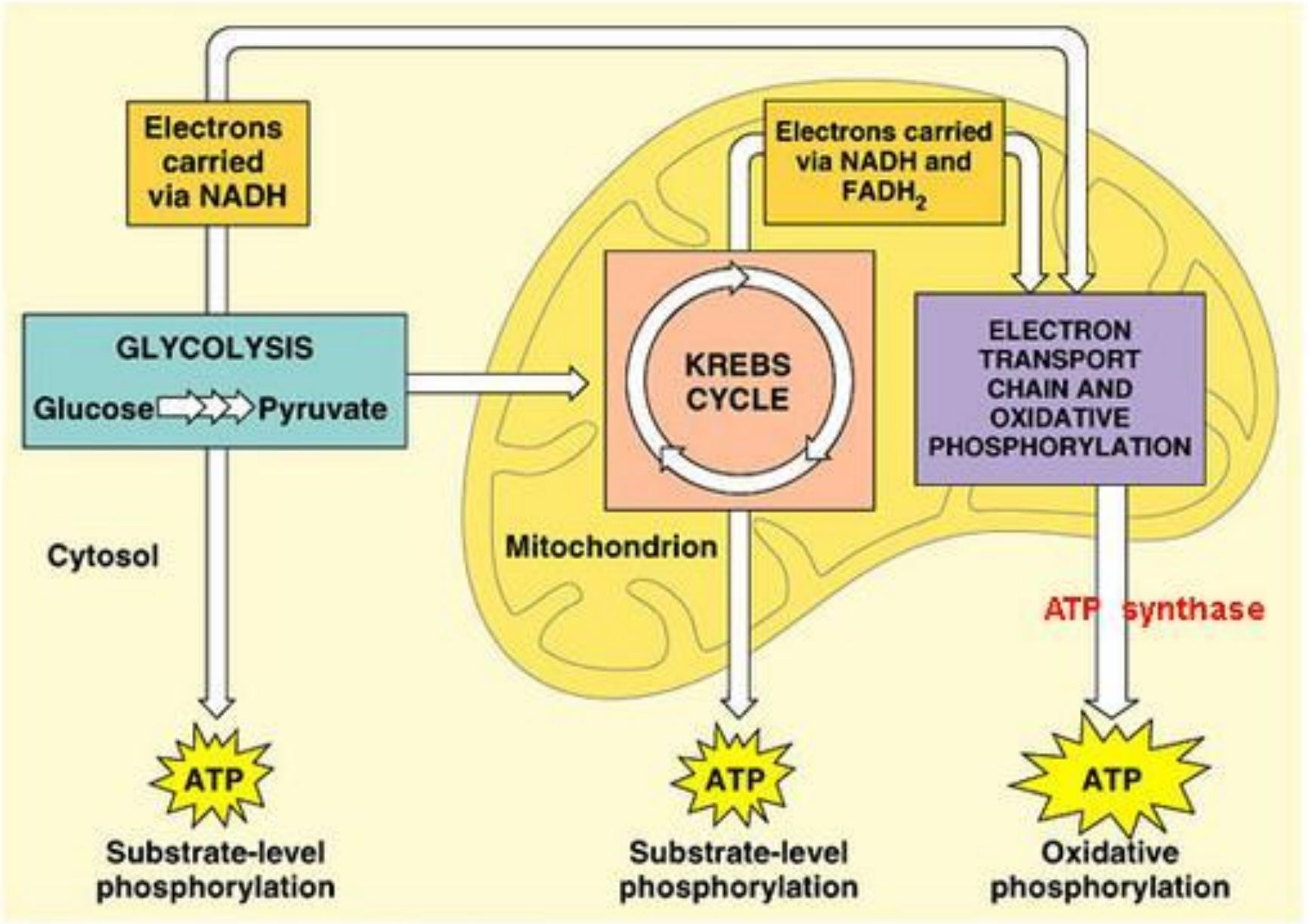
06 ATP - converted from 2 NADH – pyruvic acid breakdown phase

02 ATP - Krebs cycle (substrate-level phosphorylation)

18 ATP - converted from 6 NADH - Krebs cycle

04 ATP - converted from 2 $FADH_2$ - Krebs cycle

38 ATP - TOTAL



REVIEW:

- Overall chemical rxn for Photosynthesis →

- Overall chemical rxn for Cellular Respiration →

QUESTION:

- In addition to glucose, what other food molecules are used in Cellular Respiration?

CATABOLISM OF VARIOUS FOOD MOLECULES

- Other organic molecules used for fuel.

1. **Carbohydrates**
2. **Fats**
3. **Proteins** (amino acids)

FERMENTATION/ANAEROBIC RESPIRATION

- Occurs in **cytoplasm** when **"NO Oxygen"** is present **(called anaerobic).**
- **Remember: glycolysis is part of fermentation.**
- **Two Types:**

  1. Lactic Acid Fermentation

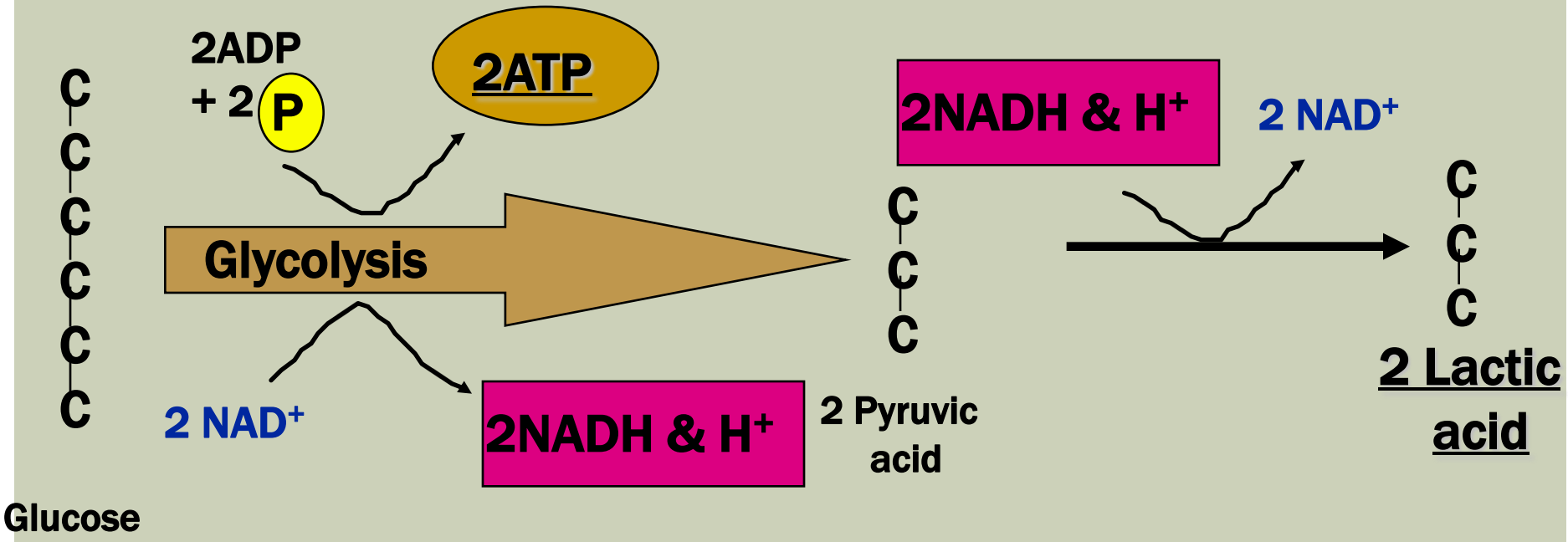
  2. Alcohol Fermentation

LACTIC ACID FERMENTATION

- Without oxygen, the 2 molecules of pyruvic acid (from glycolysis) form 2 molecules of lactic acid and 2 ATP
- Lactic acid builds up in muscle cells resulting in burning and fatigue
- Eventually lactic acid is sent to liver and converted back to pyruvic acid
  - So it can then go to C.A.C. & E.T.C when more oxygen is available
  - Pyruvic acid → acetyl coA transition

LACTIC ACID FERMENTATION

- Animals (pain in muscle after a workout).

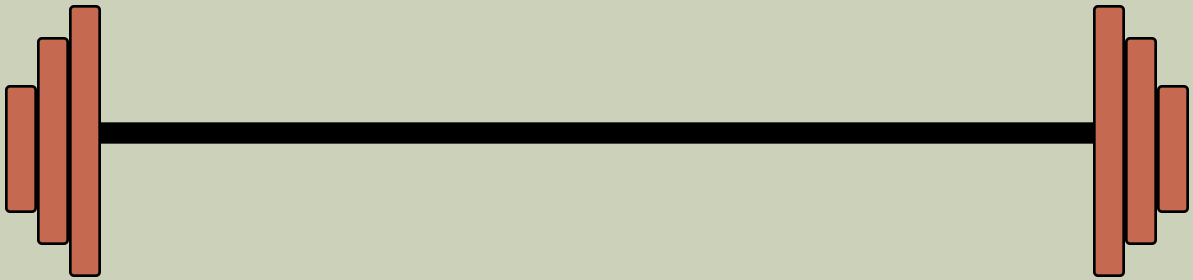


LACTIC ACID FERMENTATION

- **End Products: Lactic acid fermentation**

  2 - ATP (substrate-level phosphorylation)

  2 - Lactic Acids

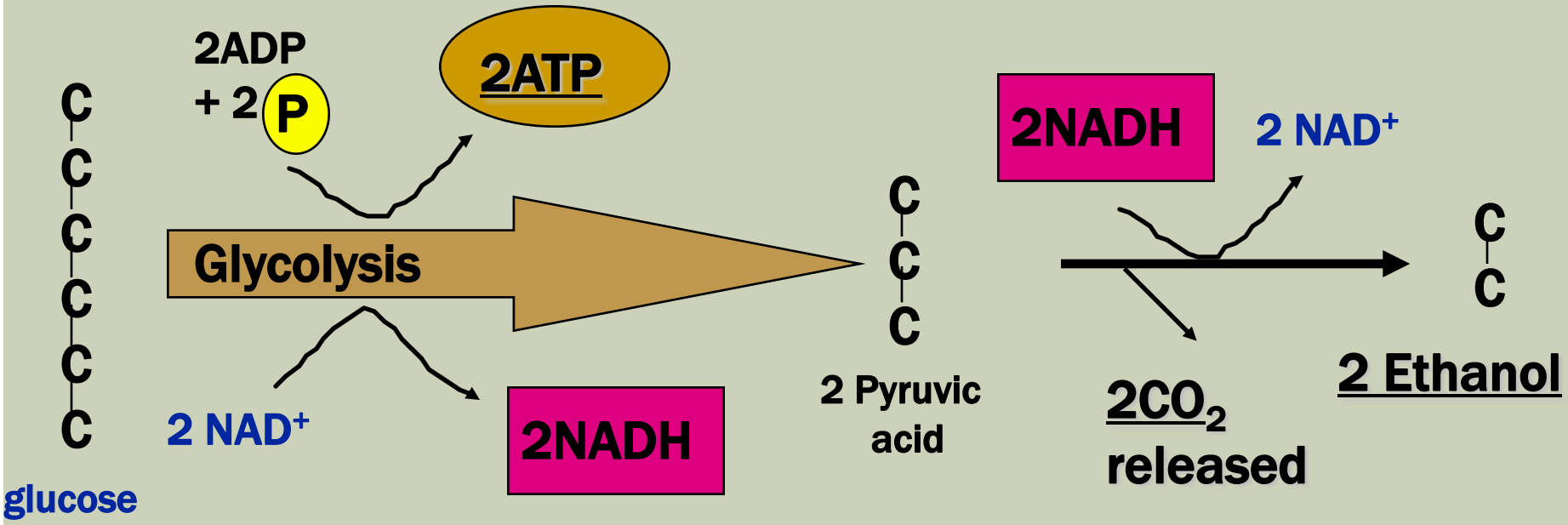


ALCOHOLIC FERMENTATION

- Used by: yeast, some bacteria
- Produced CO2 and ethyl alcohol (ethanol)
- Ex: bread, wine, alcohol

ALCOHOL FERMENTATION

- Plants and Fungi → beer and wine



ALCOHOL FERMENTATION

- **End Products: Alcohol fermentation**

  2 - ATP (substrate-level phosphorylation)

  2 - CO_2

  2 - Ethanol's

OVERALL PRODUCTS

- Glycolysis → (2) pyruvic acid, 2 ATP, ***2 CO2***
- Kreb's Cycle → 2 ATP, ***4 CO2***, 6NADH, 2FADH2
- E.T.C → 32 ATP (from carriers), ***6 H20***

- Lactic acid fermentation → 2 ATP, 2 lactic acid
- Alcoholic fermentation → 2 CO2, 2 ethyl alcohol (ethanol)

Photosynthesis

Cellular Respiration

- Location
- Product
- Uses/breaks down
- Who does it
- Light needed?
- Similarities