Ch.9: Cellular Respiration

- NEED:
  - Pencil or pen
  - Highlighter

ANTICIPATION GUIDE for CELLULAR RESPIRATION

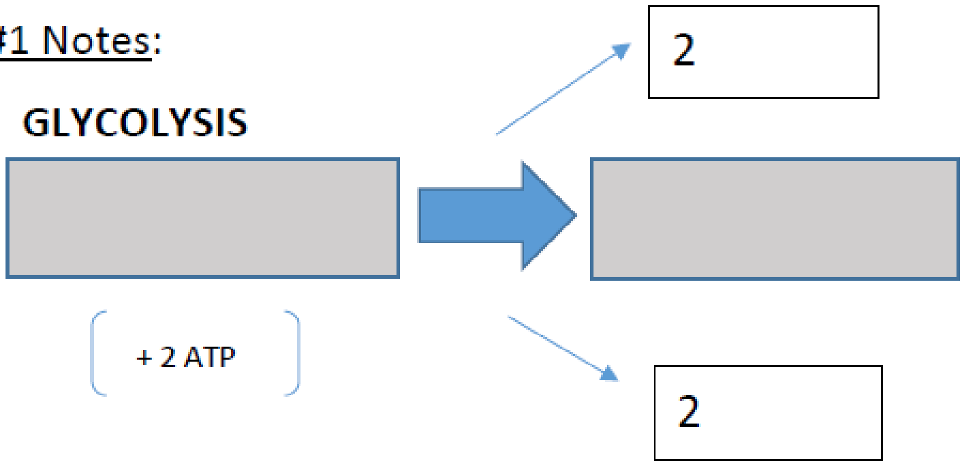
Name: ______________________________

Answer each question as best as you know in "Before" column. At the end of class you will go back and answer all of the questions in the "After" column.

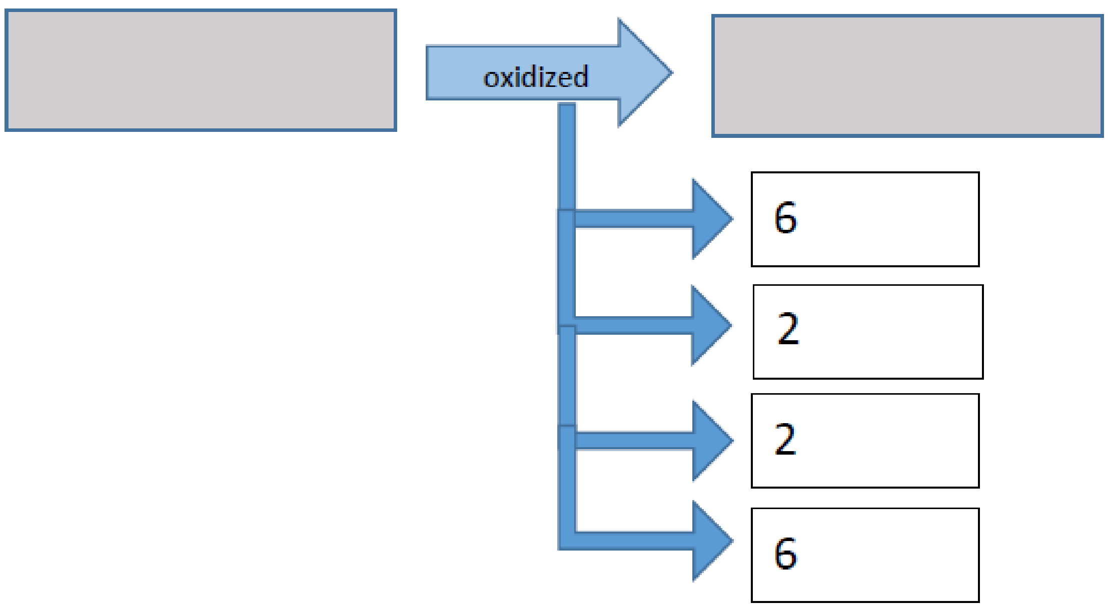
Questions	"Before" Lesson	"After" Lesson
1. To which class of biomolecules does ATP belong?		
2. What kinds of cells/organisms can do aerobic cellular respiration?		
3. What is the equation for aerobic cellular respiration?		
4. Where does glycolysis (the first step in cellular respiration) occur in a cell?		
5. In which cellular organelle does aerobic cellular respiration occur?		
6. What are the 2 main types of fermentation?		

<u>Video #1 Notes</u>:

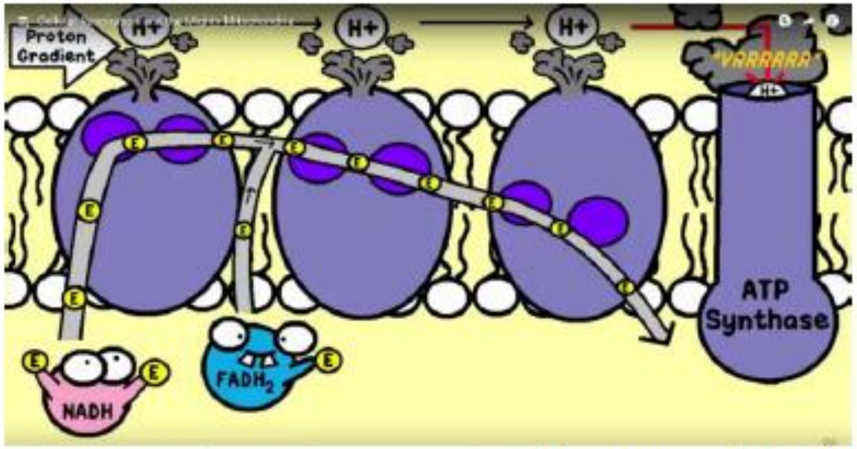
(1) GLYCOLYSIS



(2) **KREBS CYCLE** (a.k.a. "Citric Acid Cycle")



(3) ETC (ELECTRON TRANSPORT CHAIN)



__________ & ____________ are electron carriers that create a ______________ (H+) gradient. This chain utilizes many proteins with electron carriers in series. Eventually a surplus of H+ builds up on one side of the membrane and flows down their concentration gradient through the enzyme _________________. This enzyme pump generates _________ by phosphorylating ________. The final electron acceptor in the ETC is ________________. It combines with ____ protons to create ______________. Draw this last step in on the picture above.

POGIL: Cellular Respiration

- A little different today
- This will NOT be collected – you will use your findings later in class
- You must still complete all questions on your own paper
- We will do groups of 3. Please select a READER.

When your group is finished

1. Raise your hand. I will come check your work for a completion grade.

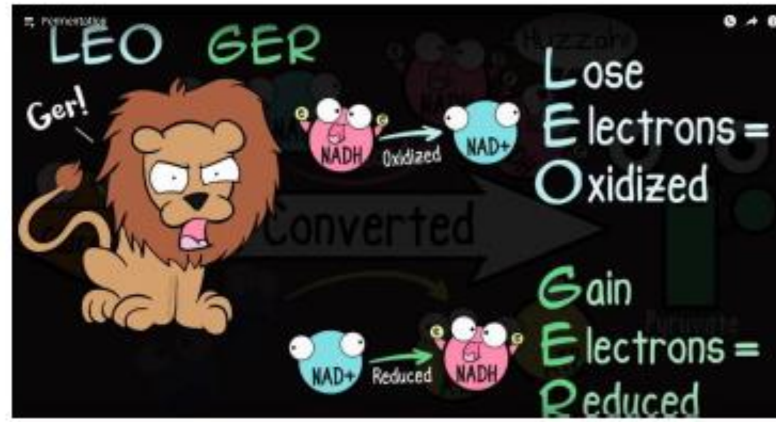
2. Go to the Student Support Station to check your answers against the answer key.

3. Make any necessary changes to your paper

4. Return to your seat, study, and wait quietly.

Video #2 Notes

1) Anaerobic respiration does not require __________. It is also called _______________________.
2) What kinds of organisms perform anaerobic respiration?



3) What are NADH (and FADH2)? What do they do?
4) Alcoholic Fermentation:
5) Lactic Acid Fermentation:

DO NOW ☺

Use your POGIL and your video notes to re-answer the questions in the "After" Column.

This is INDEPENDENT.

ANTICIPATION GUIDE for CELLULAR RESPIRATION

Name: ___________________________

Answer each question as best as you know in "Before" column. At the end of class you will go back and answer all of the questions in the "After" column.

Questions	"Before" Lesson	"After" Lesson
1. To which class of biomolecules does ATP belong?		
2. What kinds of cells/organisms can do aerobic cellular respiration?		
3. What is the equation for aerobic cellular respiration?		
4. Where does glycolysis (the first step in cellular respiration) occur in a cell?		
5. In which cellular organelle does aerobic cellular respiration occur?		
6. What are the 2 main types of fermentation?		

Let's Talk!

Exit Questions

CHECK FOR UNDERSTANDING EXIT QUESTIONS:

Name: ___________________________________

Directions: You may use your notes page from today to answer the questions. You may NOT discuss answers with your peers.

Turn this in for a grade.

Exit Questions

CHECK FOR UNDERSTANDING EXIT QUESTIONS:

Name: ___________________________________

Directions: You may use your notes page from today to answer the questions. You may NOT discuss answers with your peers.

Graded!

Pick up from front table.

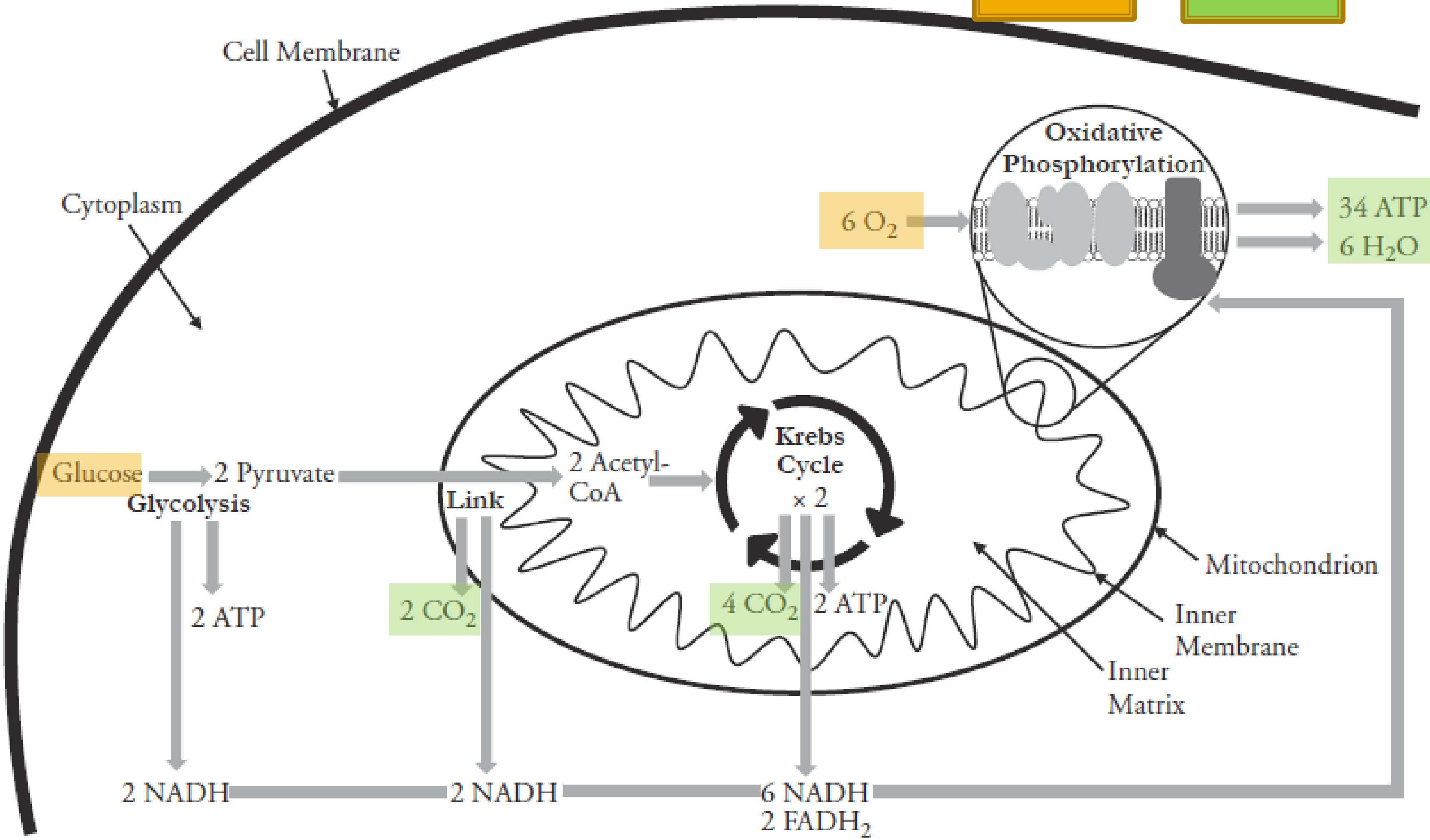
We will discuss ☺

POGIL: Cellular Respiration – An Overview

Model 1 – Cellular Respiration

#1

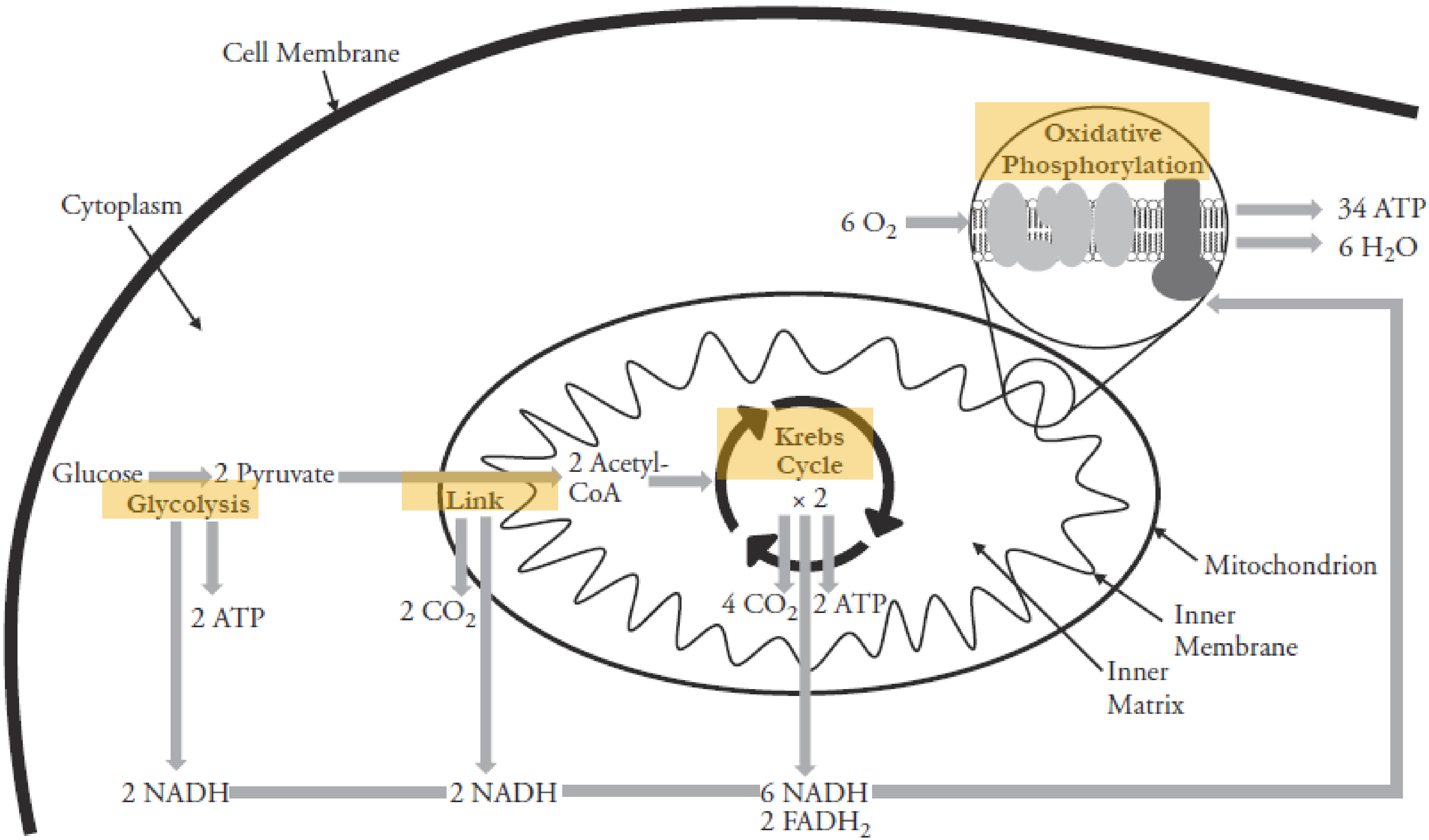
#2



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

3. Cellular respiration occurs in four phases: **glycolysis**, the **link reaction**, the **Krebs cycle**, and **oxidative phosphorylation**.

Model 1 – Cellular Respiration



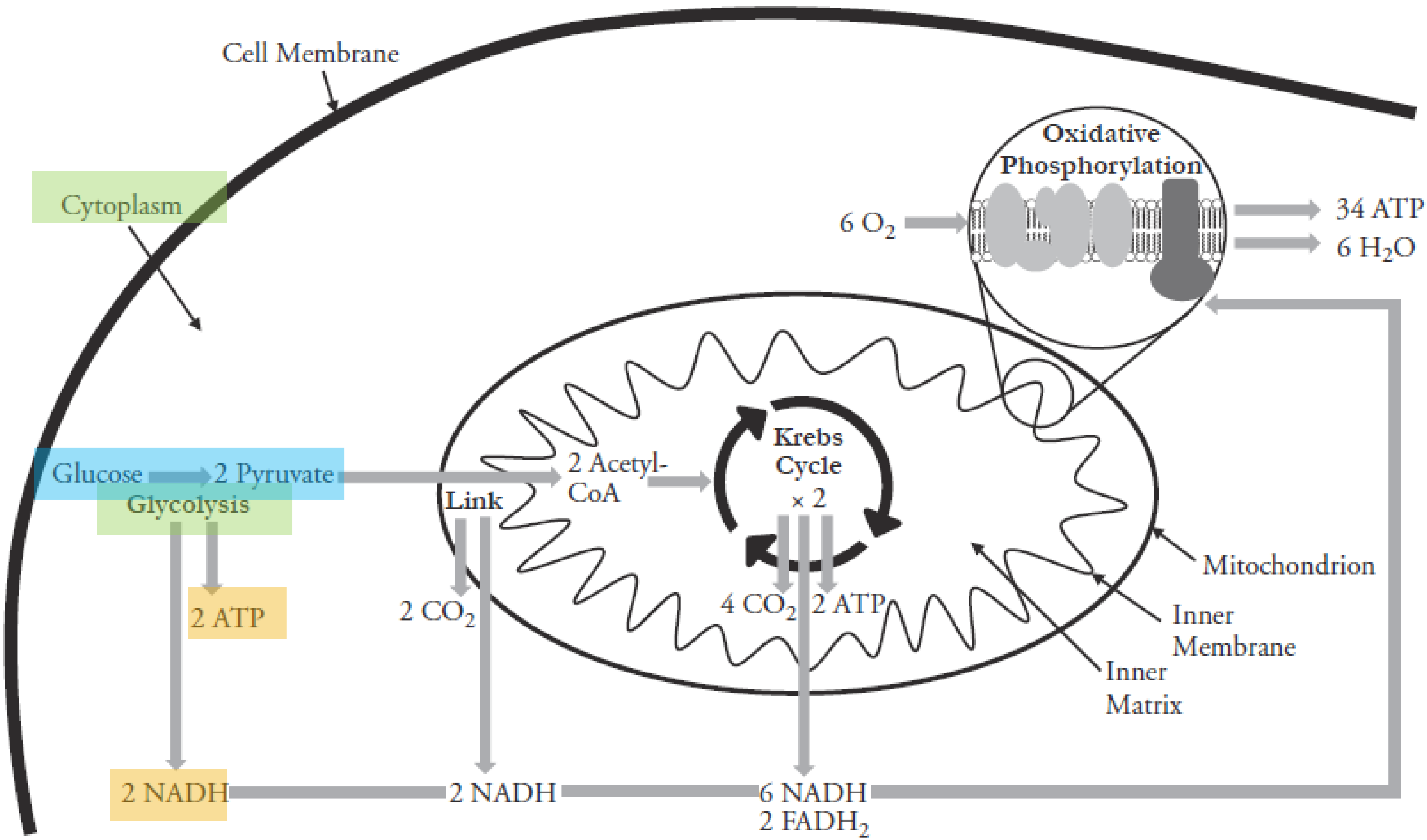
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

Ch.9 Cell Respiratation Notes

	Step in Cellular Respiration	Location in Cell	Reaction	Energy Products	"Waste" Products
	1.				
a.k.a. Pyruvate Oxidation	2.				
a.k.a. Citric Acid Cycle	3.				
ETC + Chemiosmosis	4.				

POGIL: Cellular Respiration – An Overview

Model 1 – Cellular Respiration



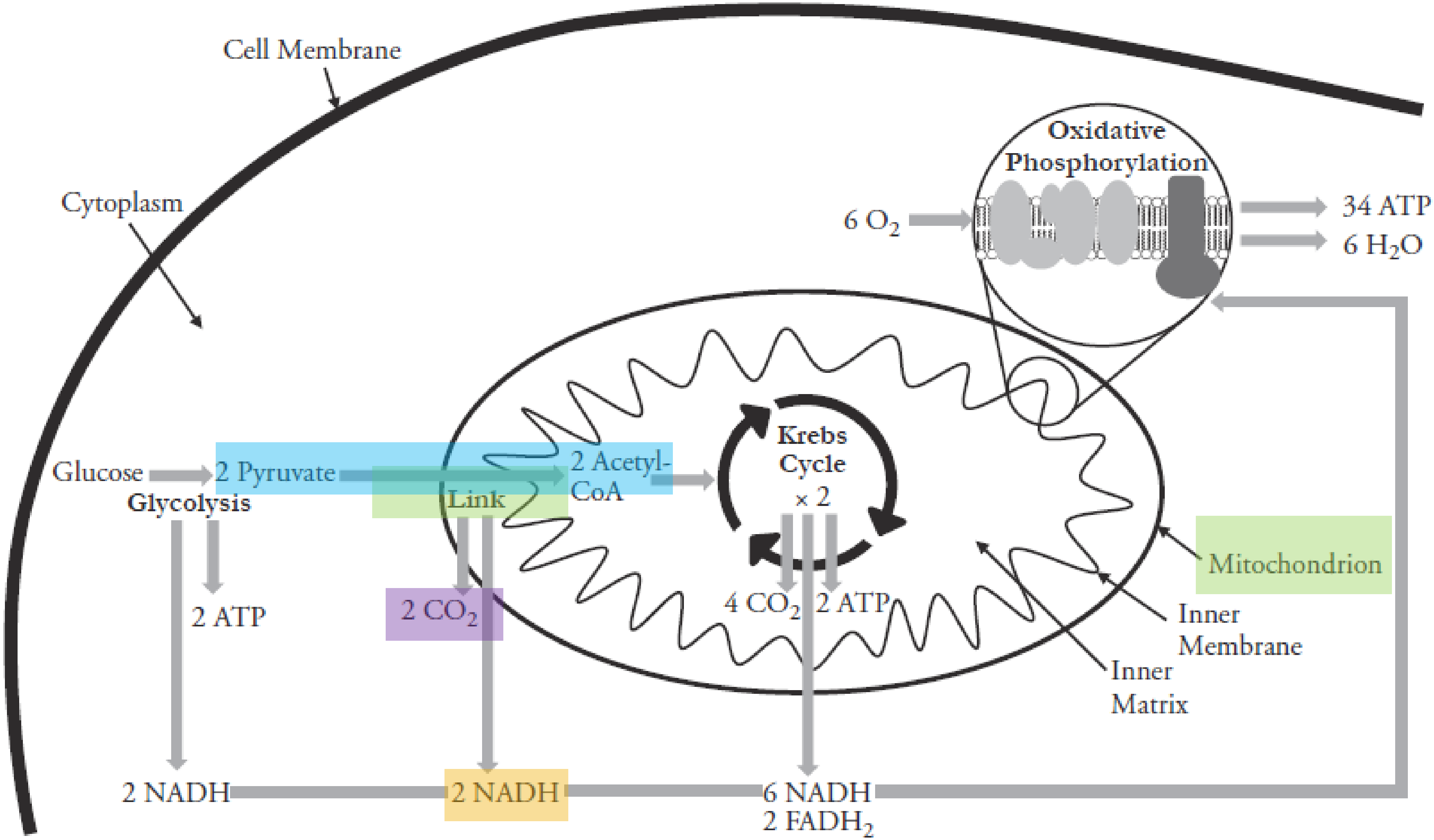
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

Notes

	Step in Cellular Respiration	Location in Cell	Reaction Input → Output	Energy Products	"Waste" Products
	1. Glycolysis	Cytoplasm	Glucose → 2 Pyruvate	2 ATP 2 NADH	
a.k.a. Pyruvate Oxidation	2.				
a.k.a. Citric Acid Cycle	3.				
ETC + Chemiosmosis	4.				

POGIL: Cellular Respiration – An Overview

Model 1 – Cellular Respiration



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

Notes

Step in Cellular Respiration	Location in Cell	Reaction Input → Output	Energy Products	"Waste" Products
1. Glycolysis	Cytoplasm	Glucose → 2 Pyruvate	2 ATP 2 NADH	
2. The Link Reaction	Mitochondria	2 Pyruvate → 2 Acetyl CoA	2 NADH	2 CO_2
3.				
4.				

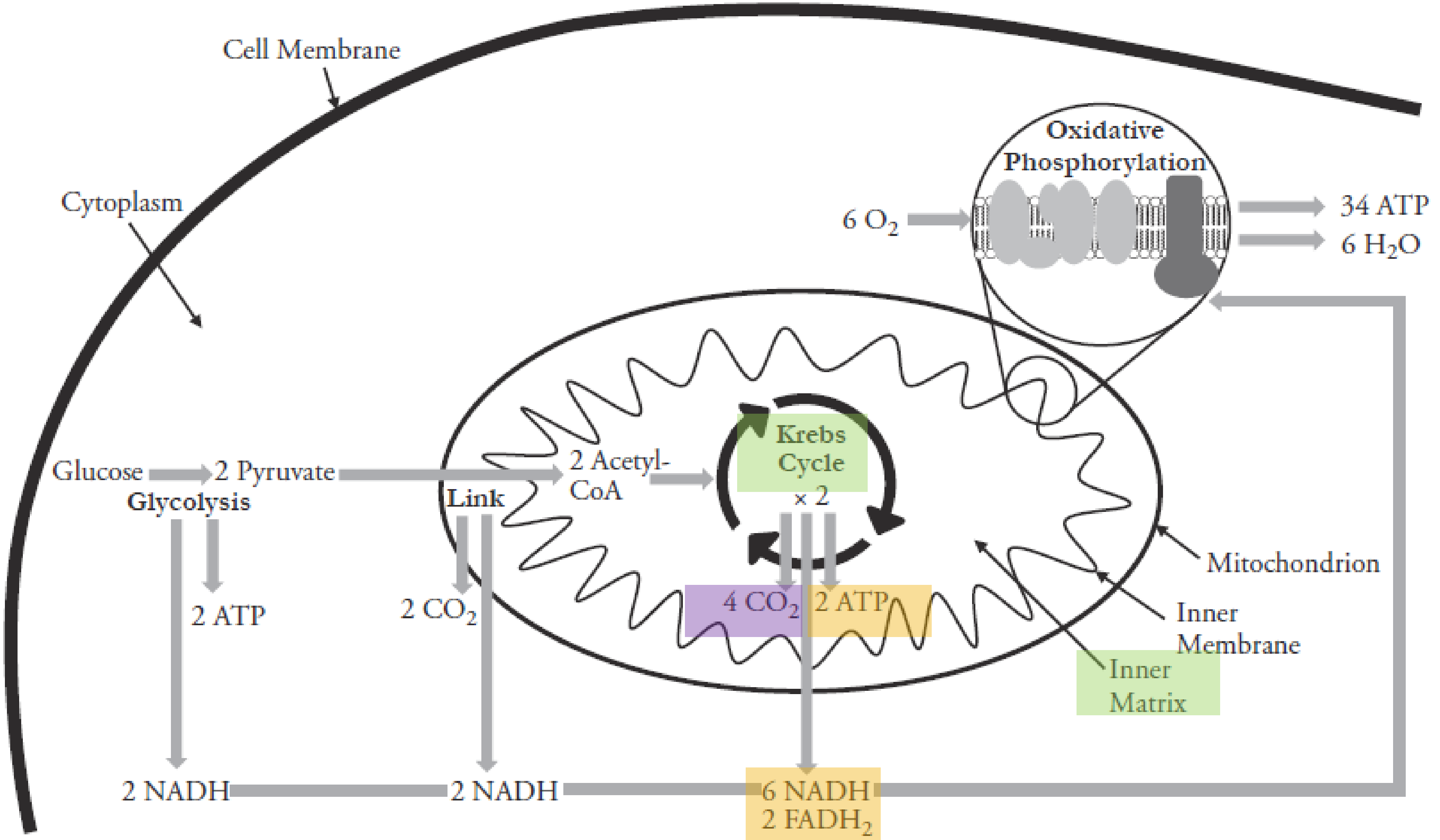
a.k.a. Pyruvate Oxidation

a.k.a. Citric Acid Cycle

ETC + Chemiosmosis

POGIL: Cellular Respiration – An Overview

Model 1 – Cellular Respiration



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

Notes

Step in Cellular Respiration	Location in Cell	Reaction Input → Output	Energy Products	"Waste" Products
1. Glycolysis	Cytoplasm	Glucose → 2 Pyruvate	2 ATP 2 NADH	
2. The Link Reaction	Mitochondria	2 Pyruvate → 2 Acetyl CoA	2 NADH	2 CO_2
3. Krebs Cycle	Inner Matrix (Mitochondria)	2 cycles Acetyl CoA → Citrate →	2 ATP 6 NADH 2 $FADH_2$	4 CO_2
4.				

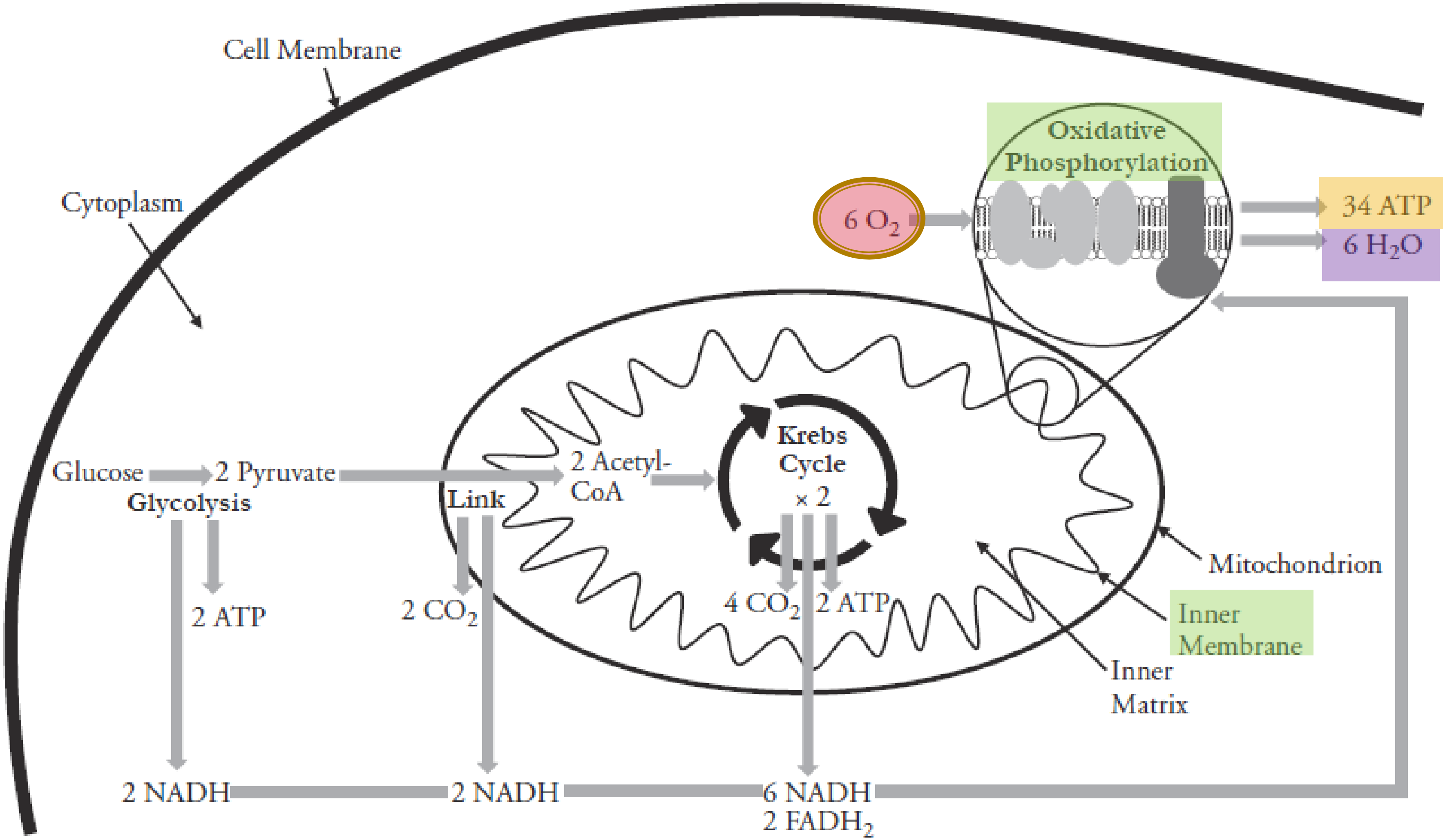
a.k.a. Pyruvate Oxidation (2. The Link Reaction)

a.k.a. Citric Acid Cycle (3. Krebs Cycle)

ETC + Chemiosmosis (4.)

POGIL: Cellular Respiration – An Overview

Model 1 – Cellular Respiration



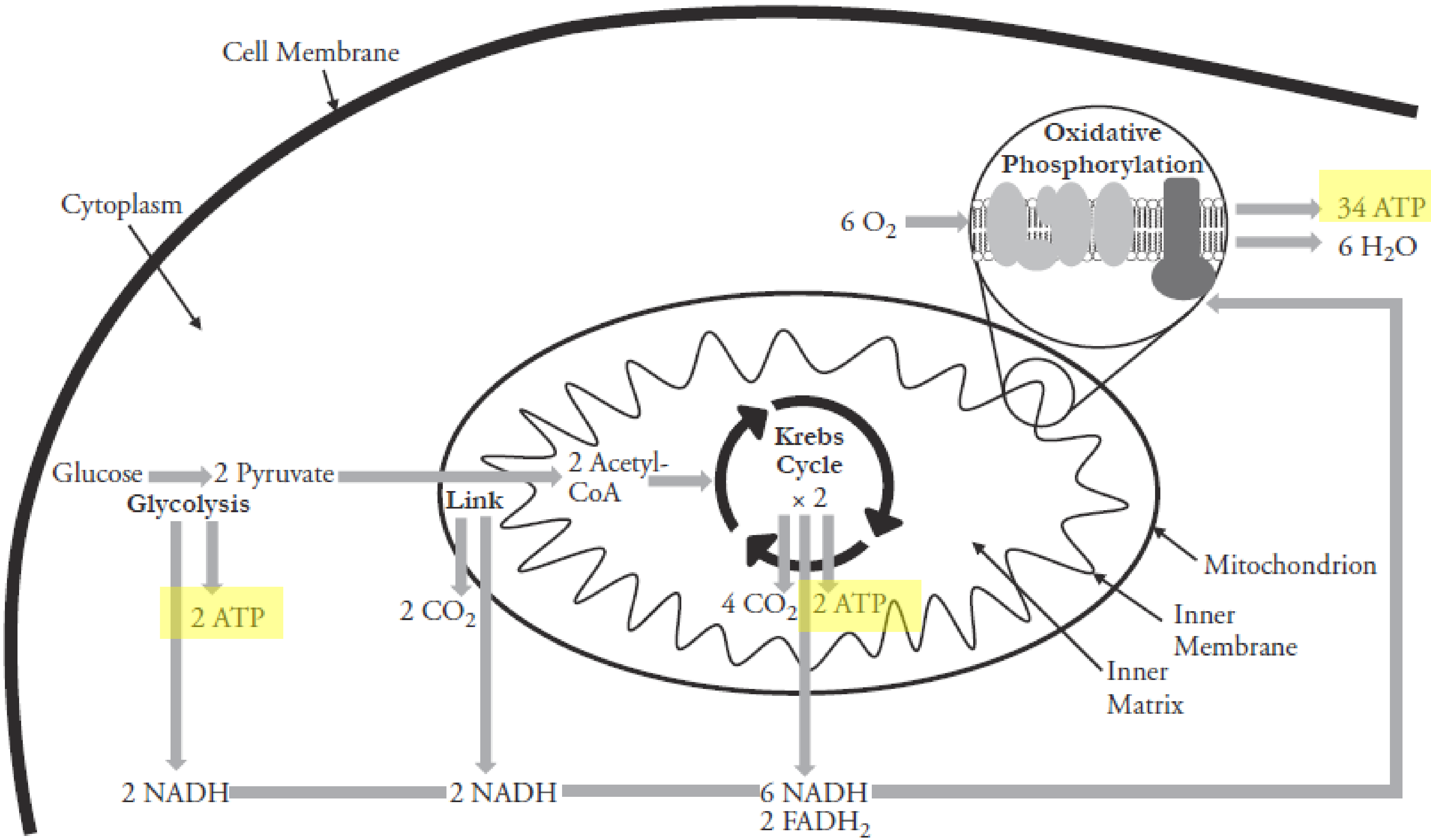
$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Energy}$$

Notes

	Step in Cellular Respiration	Location in Cell	Reaction Input → Output	Energy Products	"Waste" Products
	1. Glycolysis	Cytoplasm	Glucose → 2 Pyruvate	2 ATP 2 NADH	
a.k.a. Pyruvate Oxidation	2. The Link Reaction	Mitochondria	2 Pyruvate → 2 Acetyl CoA	2 NADH	2 CO_2
a.k.a. Citric Acid Cycle	3. Krebs Cycle	Inner Matrix (Mitochondria)	2 cycles Acetyl CoA → Citrate →	2 ATP 6 NADH 2 $FADH_2$	4 CO_2
ETC + Chemiosmosis	4. Oxidative Phosphorylation	Inner Membrane (Mitochondria	High energy electrons (from NADH & $FADH_2$) → ATP	34* ATP	6 H_2O
	TOTALS			38* ATP	6 CO_2 6 H_2O

Now answer questions 3a – 4d
Highlight the ATPs!

Model 1 – Cellular Respiration

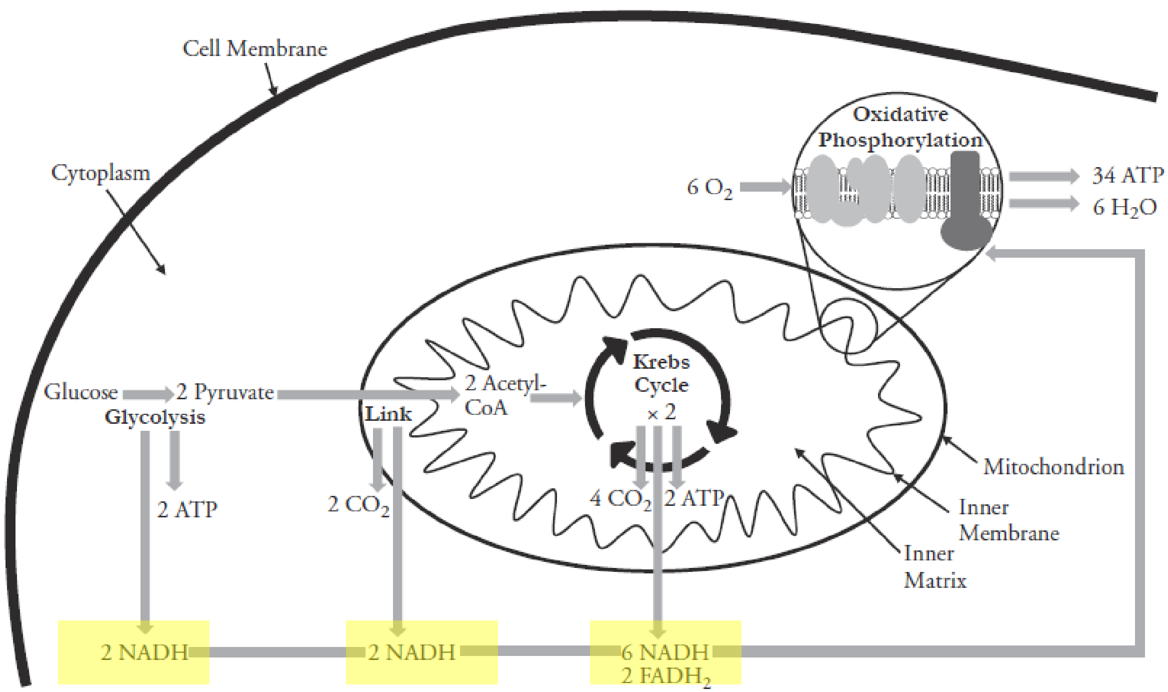


$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + Energy$$

Read This!

Glucose, or any carbon-based molecule, can be burned in oxygen (oxidized) to produce carbon dioxide and water. Combustion reactions release large amounts of energy. However, the energy release is uncontrolled. An organism would not be able to handle all that energy at once to do the work of the cell. Cellular respiration is essentially the same reaction as combustion, but the oxidation of glucose occurs in several controlled steps. The same amount of energy is ultimately released, but it is gradually released in small, controlled amounts. High potential energy molecules of ATP are produced while the carbon atoms are used to form various other molecules of lower potential energy. Each of these steps is catalyzed by an enzyme specific to that step. Model 1 illustrates the ideal circumstances for cellular respiration. In some situations, however, one glucose molecule may not result in 38 ATP molecules being produced.

Model 1 – Cellular Respiration



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

Model 2 – Electron Acceptor Molecules

$$\_\_\_\_\_\_ + NAD^{+} + H^{+} \longrightarrow NADH$$

$$\_\_\_\_\_\_ + FAD + 2H^{+} \longrightarrow FADH_2$$

$$\_\_\_\_\_\_ + \tfrac{1}{2}O_2 + 2H^{+} \longrightarrow H_2O$$

6. Nicotinamide adenine dinucleotide (NAD^+) and flavin adenine dinucleotide (FAD) are coenzymes used in cellular respiration to transport high potential energy electrons to the electron transport chain (a step in oxidative phosphorylation) in the mitochondria. At the conclusion of cellular respiration, oxygen is the final electron acceptor. The reactions in Model 2 show these electron acceptors in the process of picking up an electron.

   a. How many ele…

   … hydrogen ion wi… …ge likely to be attracted to NAD^+, F… … O_2 without …n input of free energy? Explain y…

Read This!

Oxidation is a loss of electrons. Reduction is a gain of electrons. The two processes must go hand-in-hand. In other words, electrons cannot be added to something from thin air, they must have been taken off of something first.

8. Are the reactions in Model 2 oxidati...

9. ...nine dinucleotide is the “reduced” form, NAD...
...ur rea...

...cording to Model 1, glucose undergoes ... during cellular respiration. ...tep NADH or $FADH_2$ is produced. Is gluco... ...duced during ce... ...? Explain your reasoning.

... ⟶ acetyl-CoA ⟶ carbon dioxide

14. Cells can survive for short periods without oxygen. Only the glycolysis phase of cellular respiration occurs in those circumstances.

Model 3 (15-20 only)

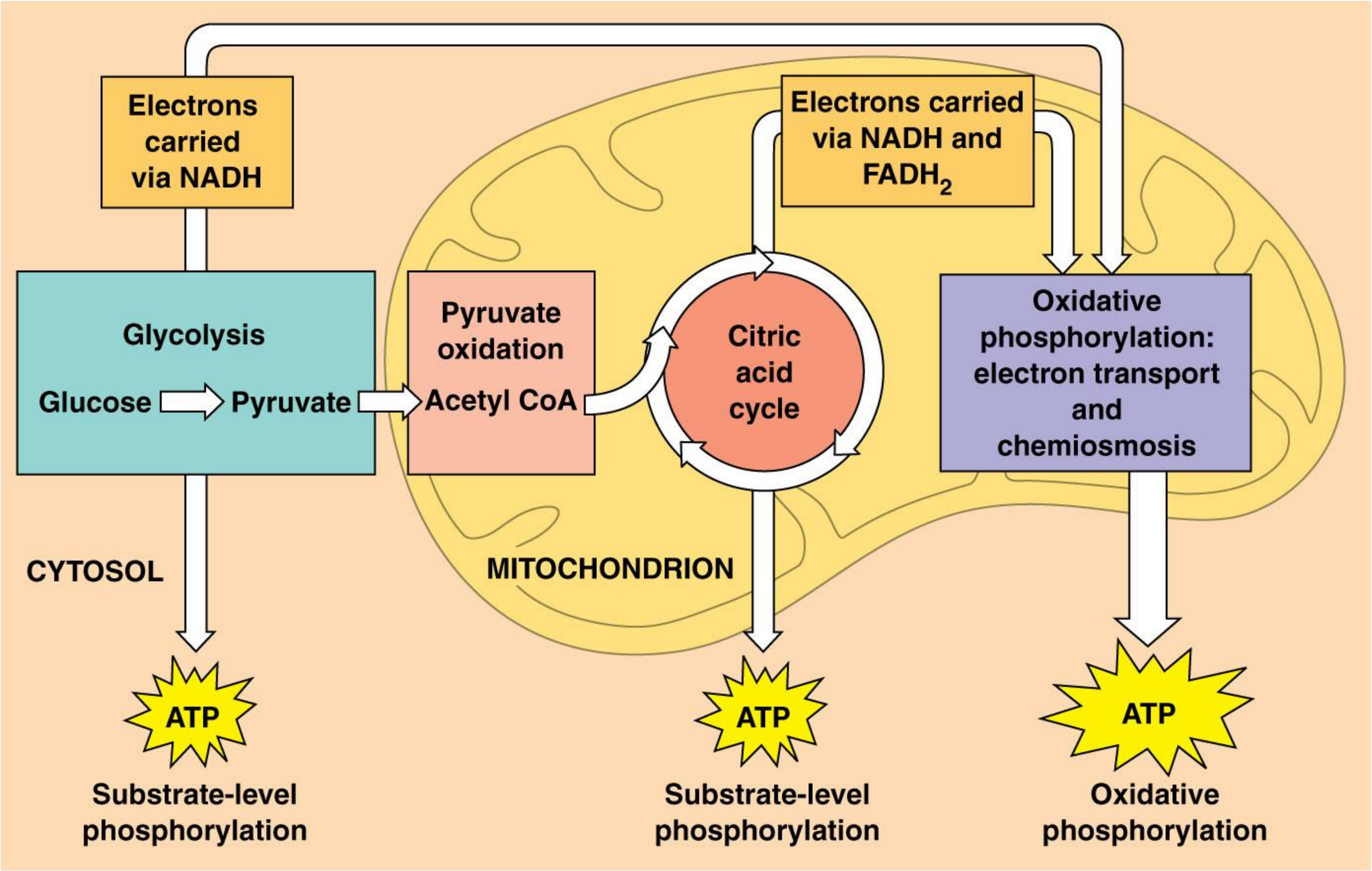
- Work through Model 3 in small groups / pairs

Chapter 9: Respiration

Stages of Cellular Respiration

1. Glycolysis
2. Pyruvate Oxidation + Citric Acid Cycle (Krebs Cycle)
3. Oxidative Phosphorylation (electron transport chain (ETC) & chemiosmosis)

Overview of Cellular Respiration



Cellular Respiration

Stage 1: Glycolysis

Glycolysis

- Breaking down glucose
  - "glyco – lysis" (sugar splitting)

glucose → → → → → pyruvate

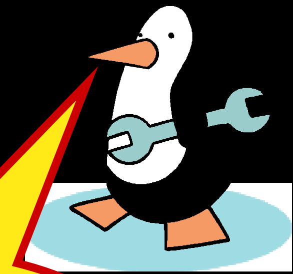
6C — 2x 3C

  - ancient pathway which harvests energy
    - where energy transfer **first evolved**
    - transfer energy from organic molecules to ATP
    - still is **starting point for ALL cellular respiration**
  - but it's **inefficient**
    - generate only 2 ATP for every 1 glucose
  - occurs in **cytosol**

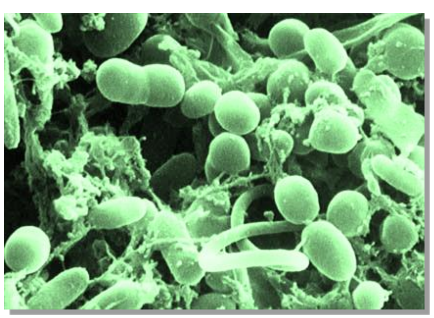
TURN & TALK

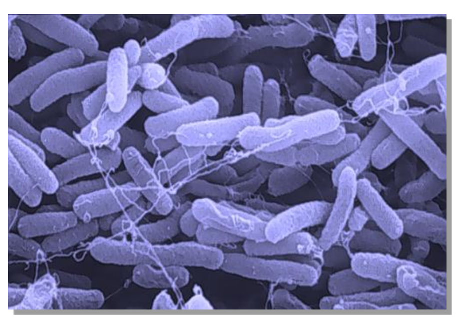
Why does it make sense EVOLUTIONARILY that Glycolysis occurs in cytoplasm?

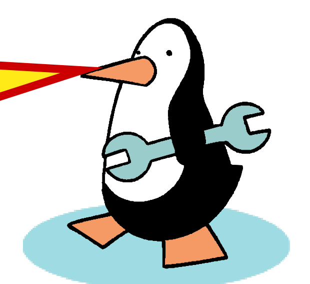
Evolutionary perspective



- **Prokaryotes**
  - first cells had no organelles
- **Anaerobic atmosphere**
  - life on Earth first evolved without free oxygen (O_2) in atmosphere
  - energy had to be captured from organic molecules in absence of O_2
- **Prokaryotes that evolved glycolysis are ancestors of all modern life**
  - ALL cells still utilize glycolysis







Glycolysis Overview

- "sugar splitting"
- Believed to be ancient (early prokaryotes - no O_2 available)
- **Location**: cytosol
- **Reaction**:
  - Partially oxidizes glucose (6C) to 2 pyruvates (3C)
- **Consumes**: 2 ATP
- **Net Yield**: **2 ATP** **+** **2NADH**
- Also makes **$2H_2O$**
- No O_2 required

Glycolysis

Stage 1: Energy Investment Stage

- Cell uses ATP to phosphorylate compounds of glucose

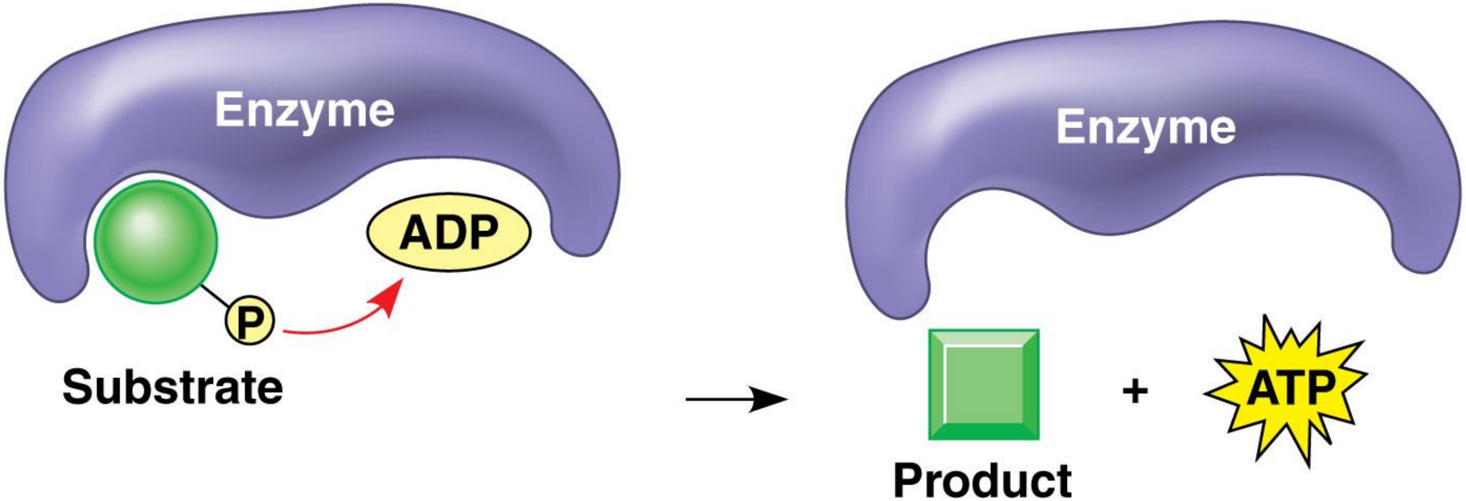
Stage 2: Energy Payoff Stage

- Two 3-C compounds oxidized
- For each glucose molecule:
  - 2 Net **ATP** produced by substrate-level phosphorylation
  - 2 molecules of NAD^+ → **NADH**

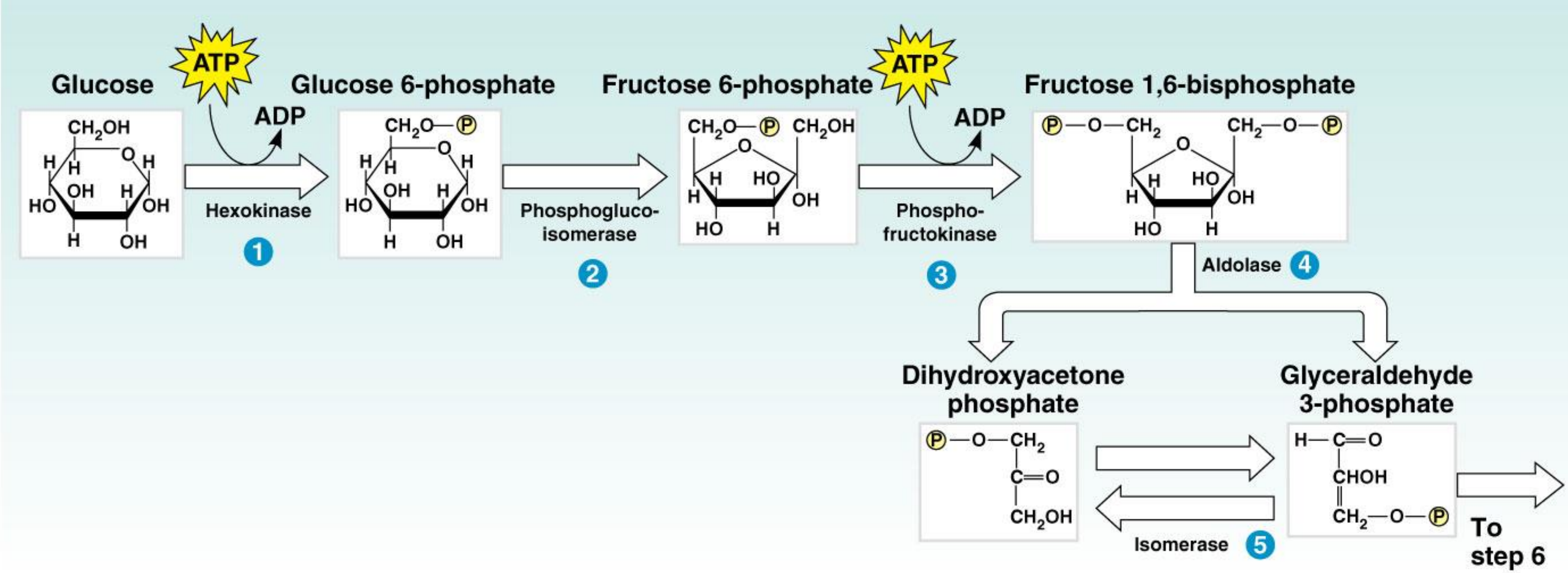
Substrate-Level Phosphorylation

- Generate small amount of **ATP**
- **Phosphorylation**: enzyme transfers a phosphate to other compounds

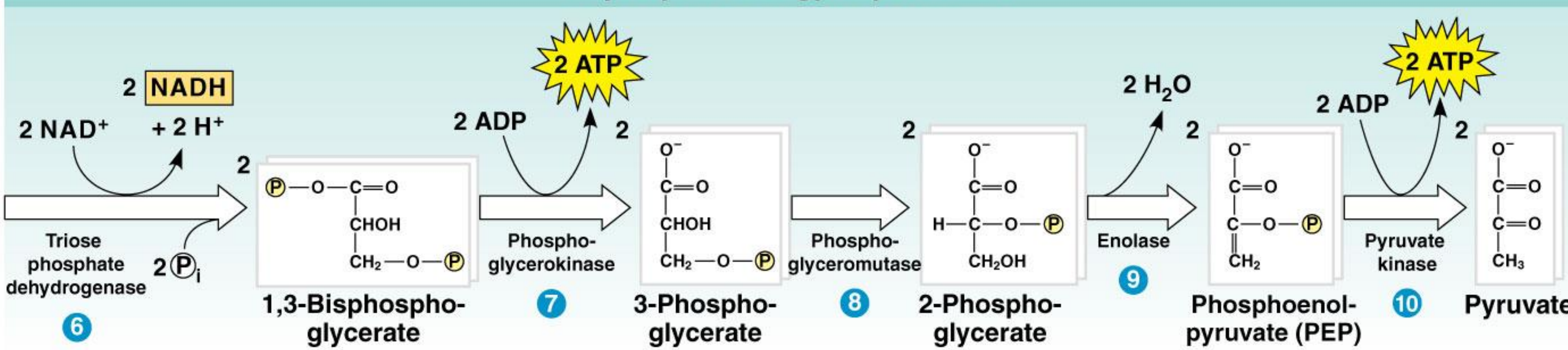
- ADP (substrate) + P_i → **ATP**



Glycolysis: Energy Investment Phase

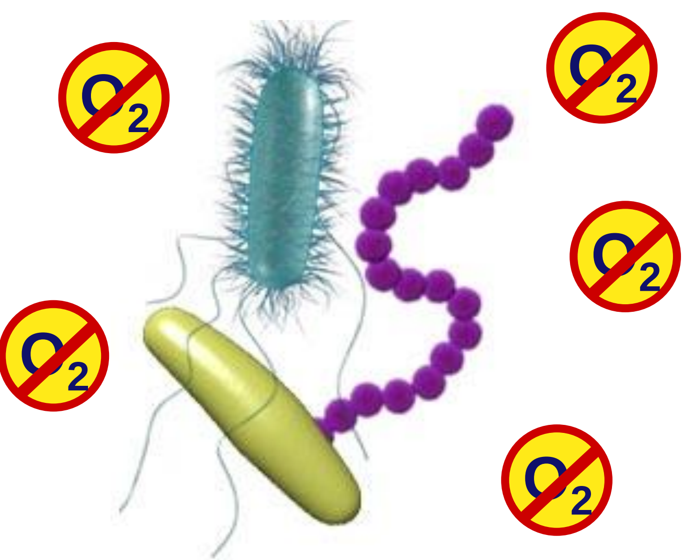


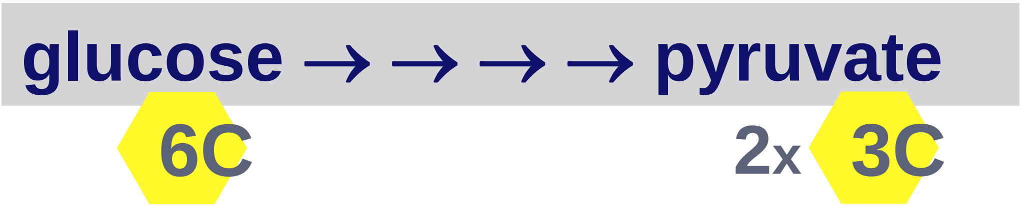
Glycolysis: Energy Payoff Phase



Is that all there is?

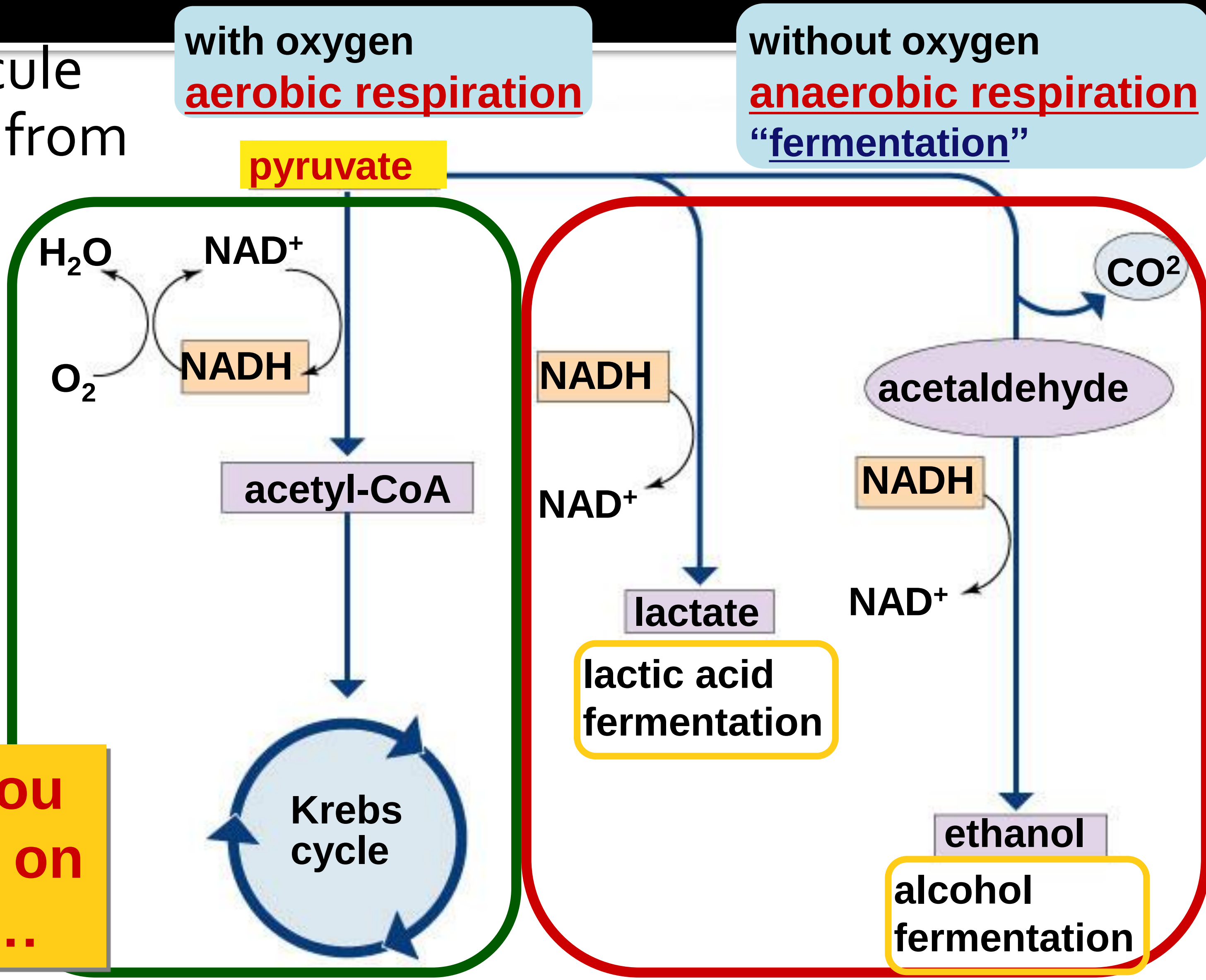
- Not a lot of energy…
  - for 1 billon years[+] this is how life on Earth survived
    - no O_2 = **slow growth, slow reproduction**
    - only harvest 3.5% of energy stored in glucose
      - more carbons to strip off = more energy to harvest





How is NADH recycled to NAD^+?

Another molecule must accept H from NADH



which path you use depends on who you are…

Fermentation (anaerobic)

- **Bacteria, yeast**

pyruvate → ethanol + CO_2

3C → 2C + 1C

NADH → NAD^+

back to glycolysis→→

  - beer, wine, bread

- **Animals, some fungi**

pyruvate → lactic acid

3C → 3C

NADH → NAD^+

back to glycolysis→→

  - cheese, anaerobic exercise (no O_2)

Alcohol Fermentation

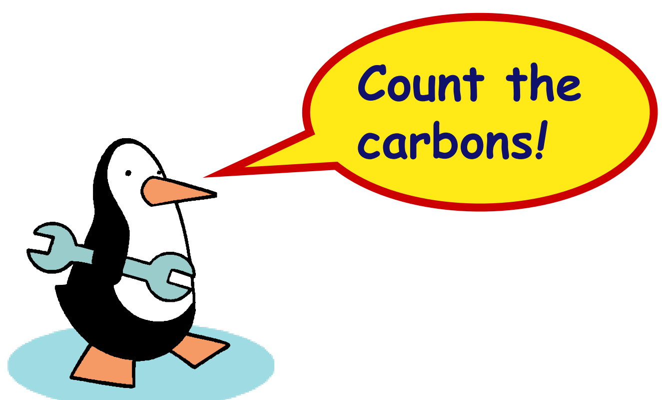
bacteria yeast

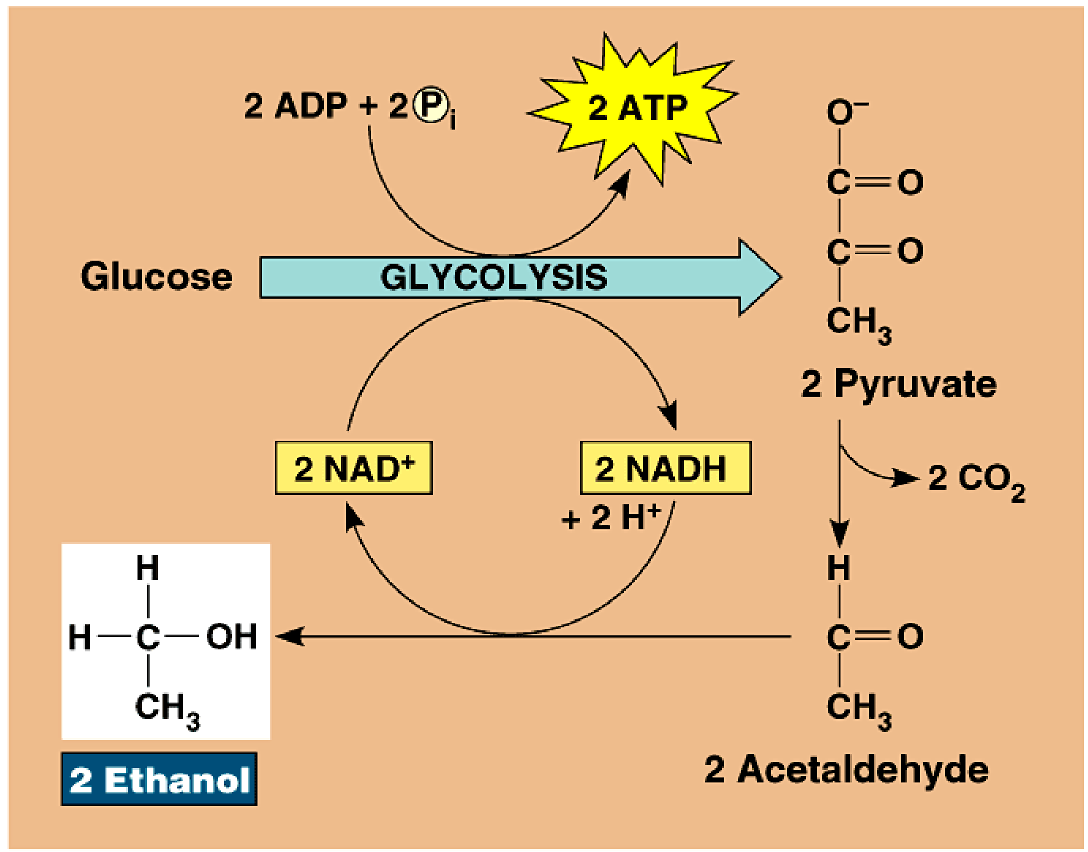
pyruvate → ethanol + CO_2

3C ↷ 2C 1C

NADH NAD$^+$ back to glycolysis→→

- Dead end process
  - at ~12% ethanol, kills yeast
  - can't reverse the reaction



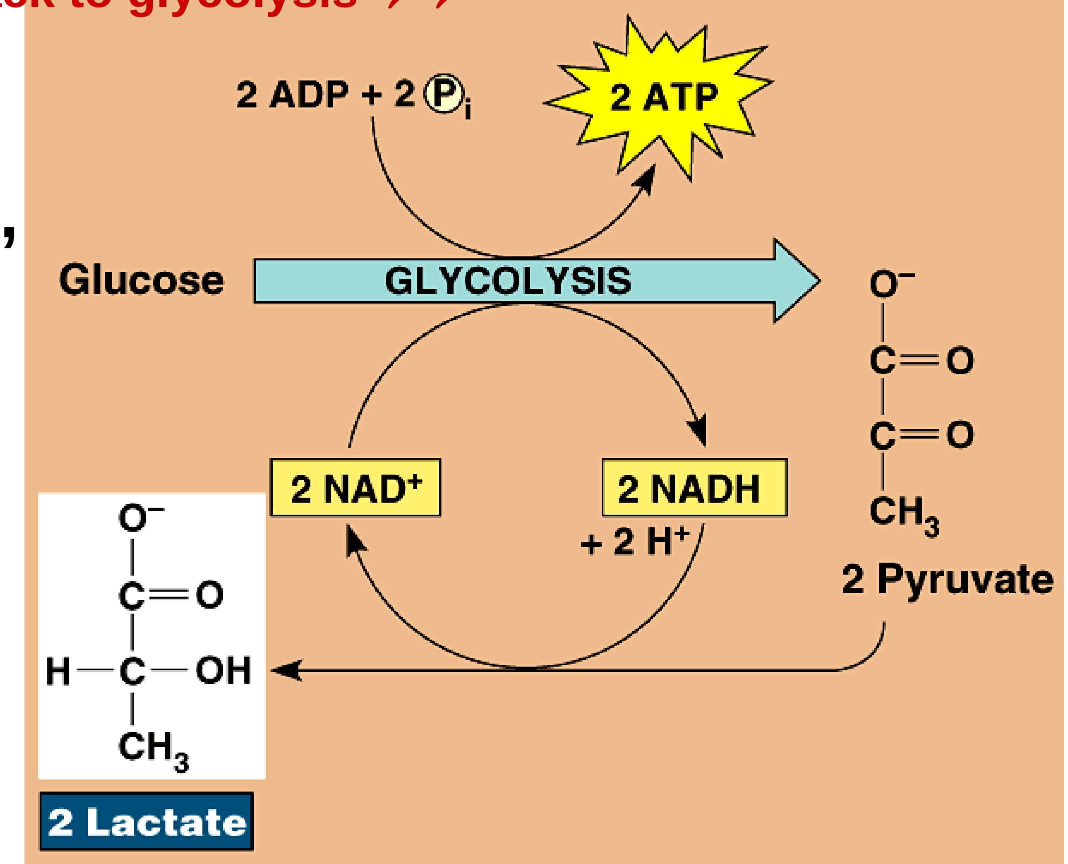


Lactic Acid Fermentation

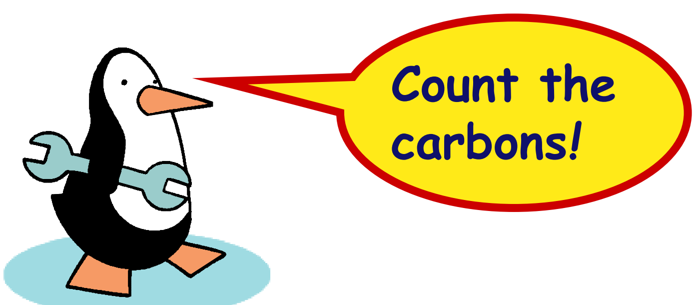
pyruvate ⇄ lactic acid (O_2)

3C　　　　3C

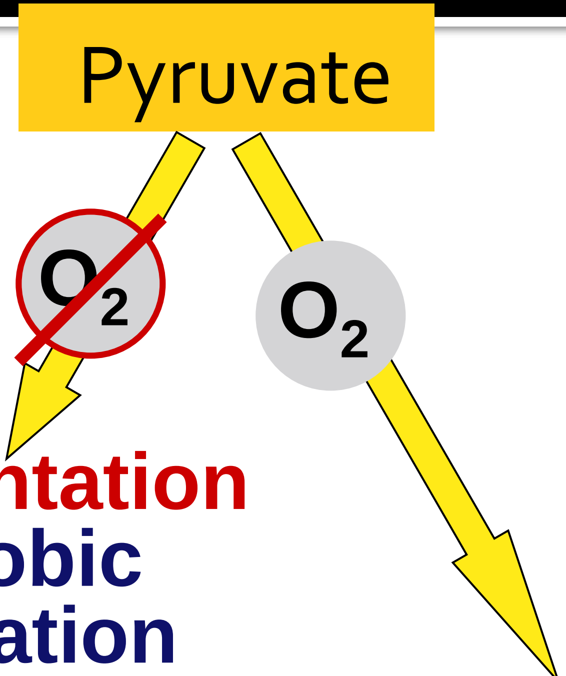
NADH　　NAD^+ back to glycolysis→→



- **Reversible process**
  - **once O_2 is available, lactate is converted back to pyruvate by the liver**

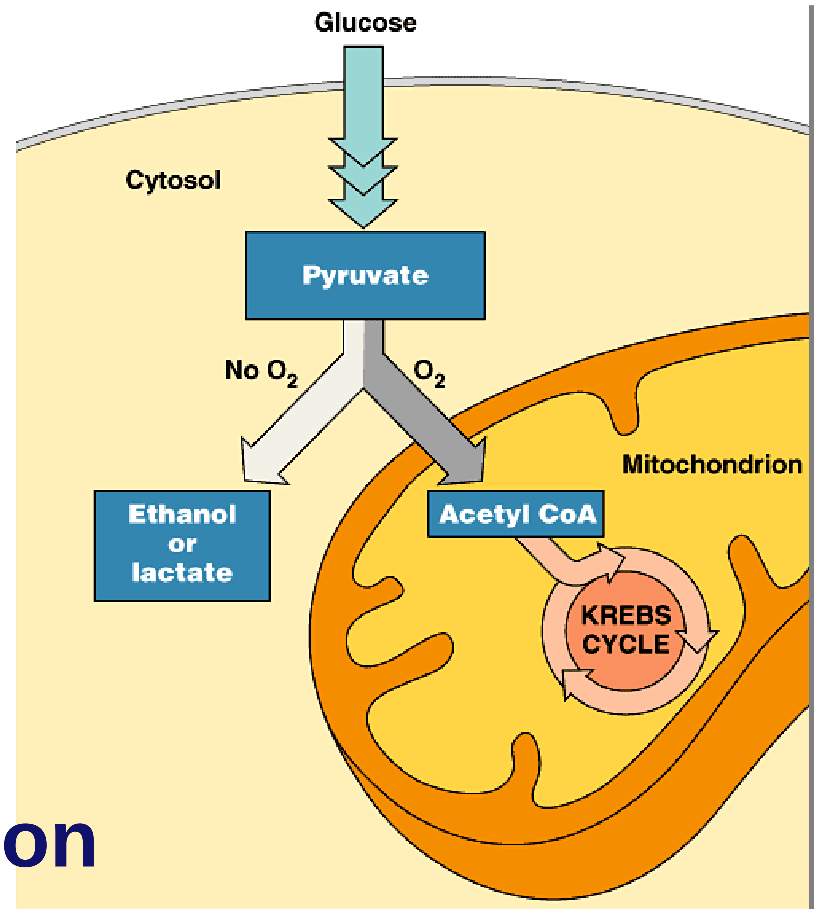


Pyruvate is a branching point



fermentation
anaerobic respiration

mitochondria
Krebs cycle
aerobic respiration



Glycolysis (Summary)

Now take 5 minutes and write a PARAGRAPH summary of glycolysis in your notes.

POGIL: Model 1: Glycolysis

- Work through Model 1 of the POGIL.
- Then STOP.

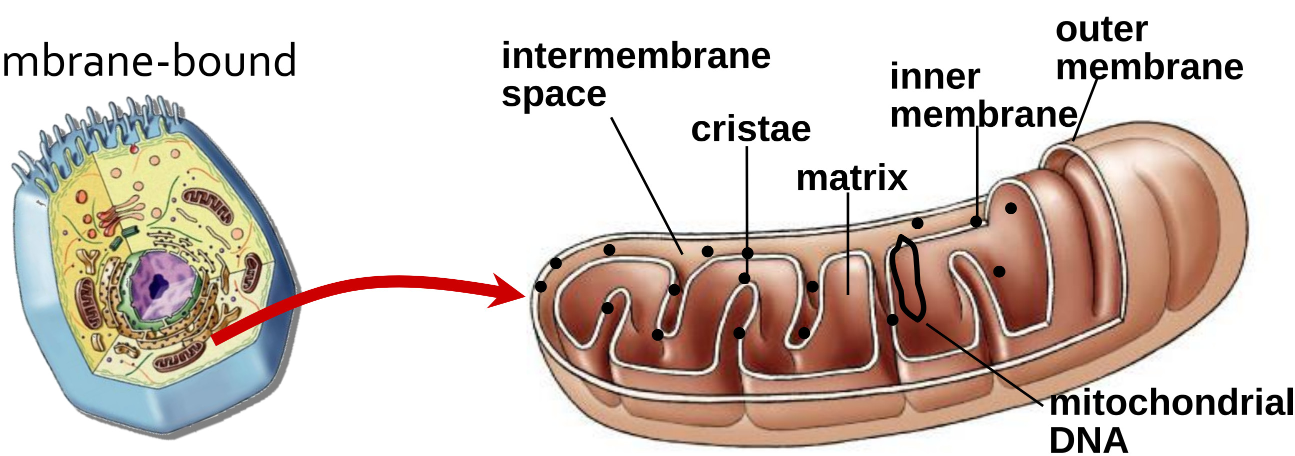
Cellular Respiration

Stage 2: Pyruvate Oxidation + Citric Acid Cycle [Krebs Cycle]

Mitochondria — Structure

- Double membrane energy harvesting organelle
  - smooth outer membrane
  - highly folded inner membrane
    - cristae
  - intermembrane space
    - fluid-filled space between membranes
  - matrix
    - inner fluid-filled space
  - DNA, ribosomes
  - enzymes
    - free in matrix & membrane-bound

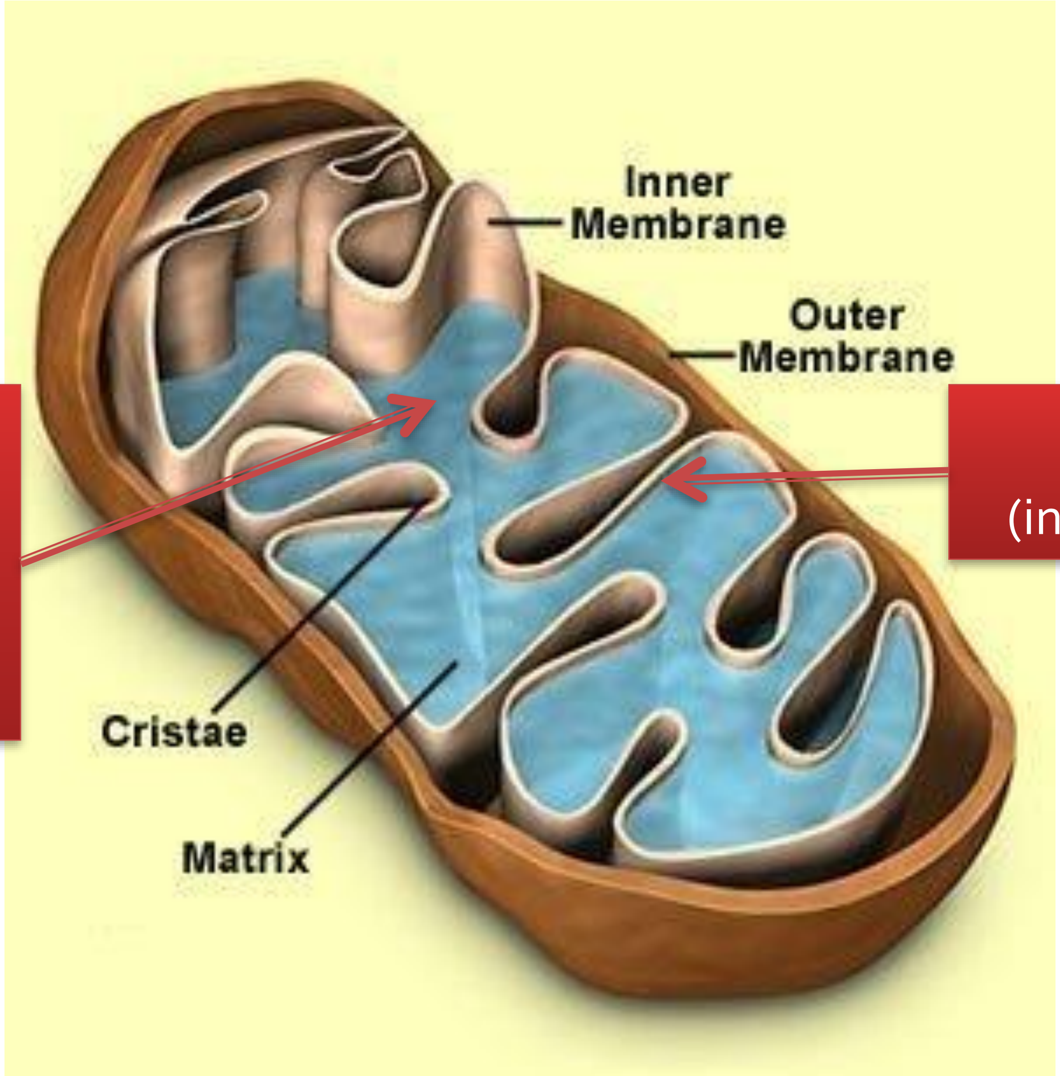
What cells would have a lot of mitochondria?



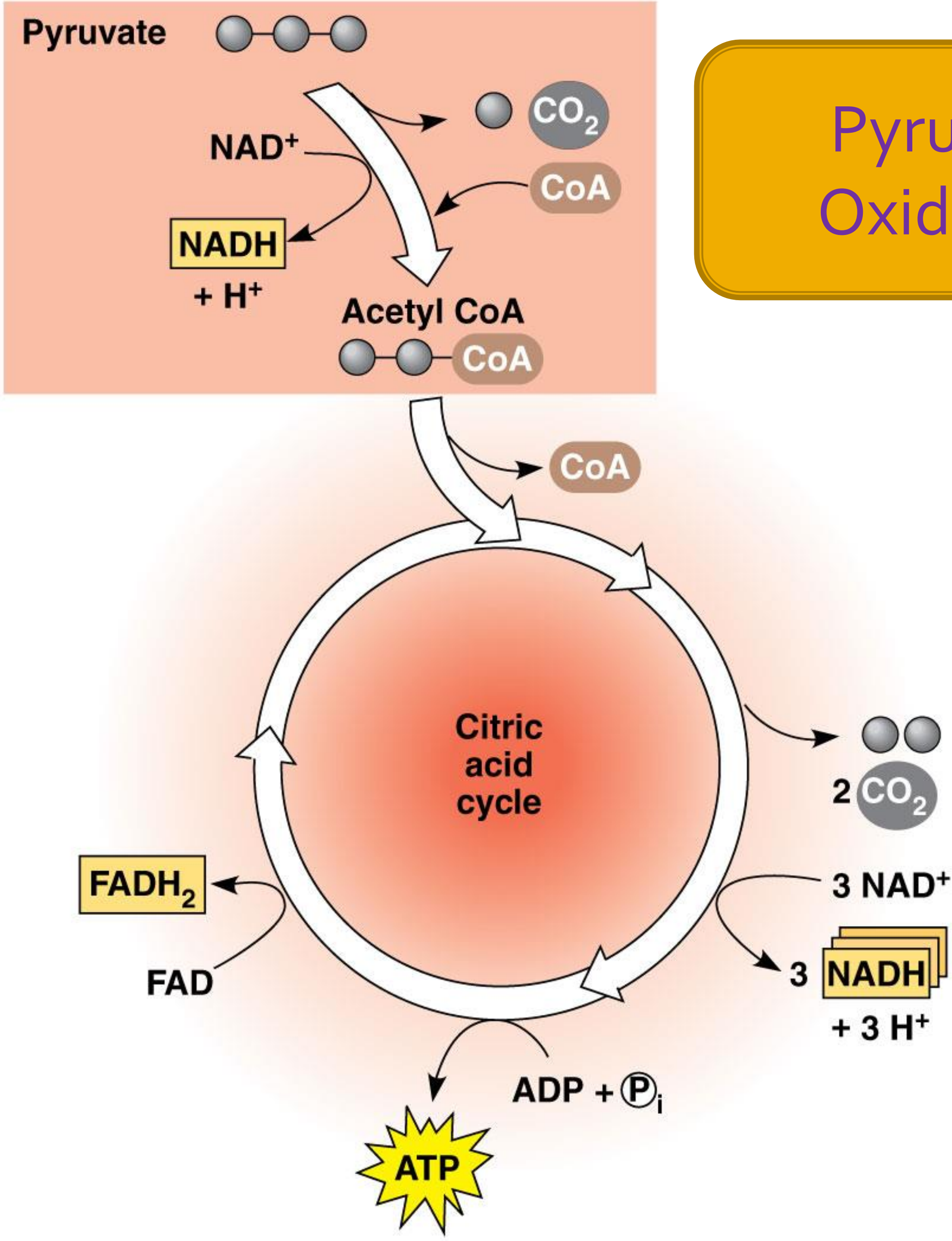
Mitochondrion Structure

Citric Acid Cycle (Krebs) (matrix)

ETC (inner membrane)

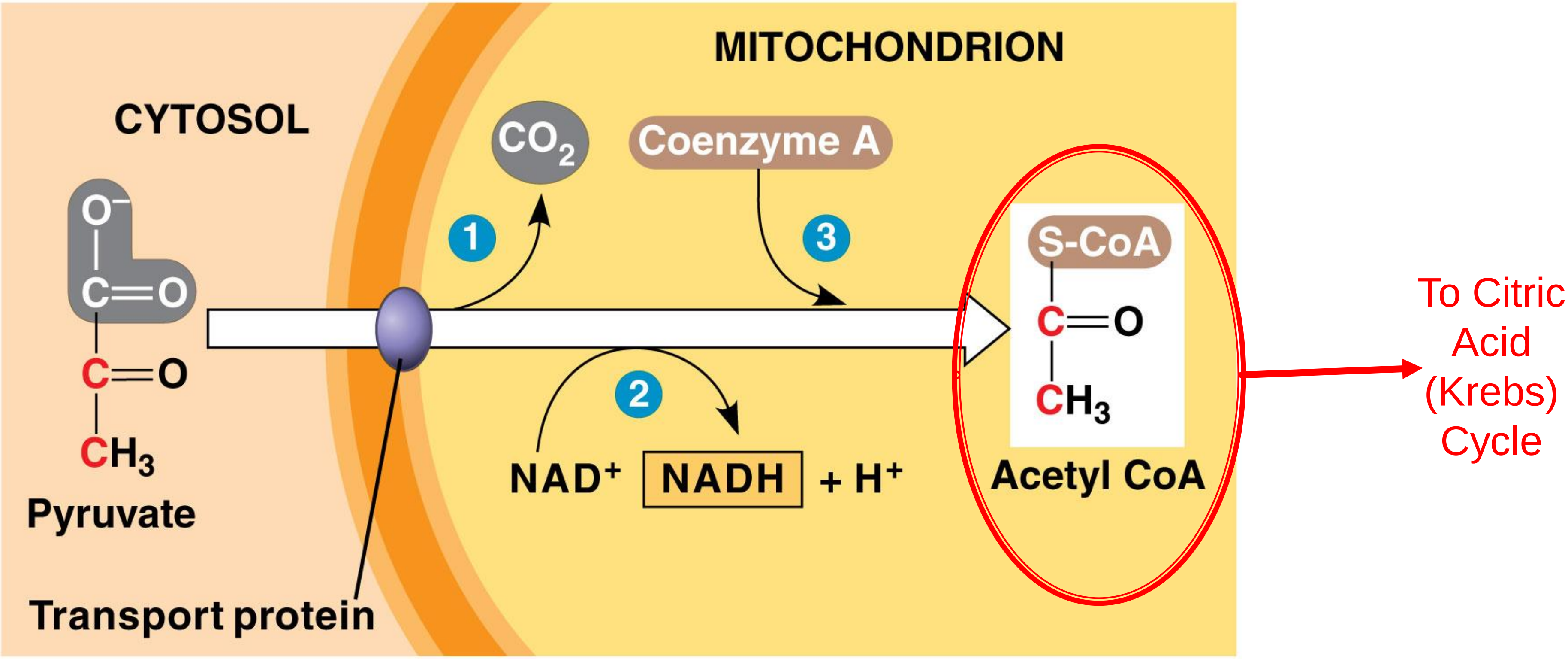


Pyruvate Oxidation



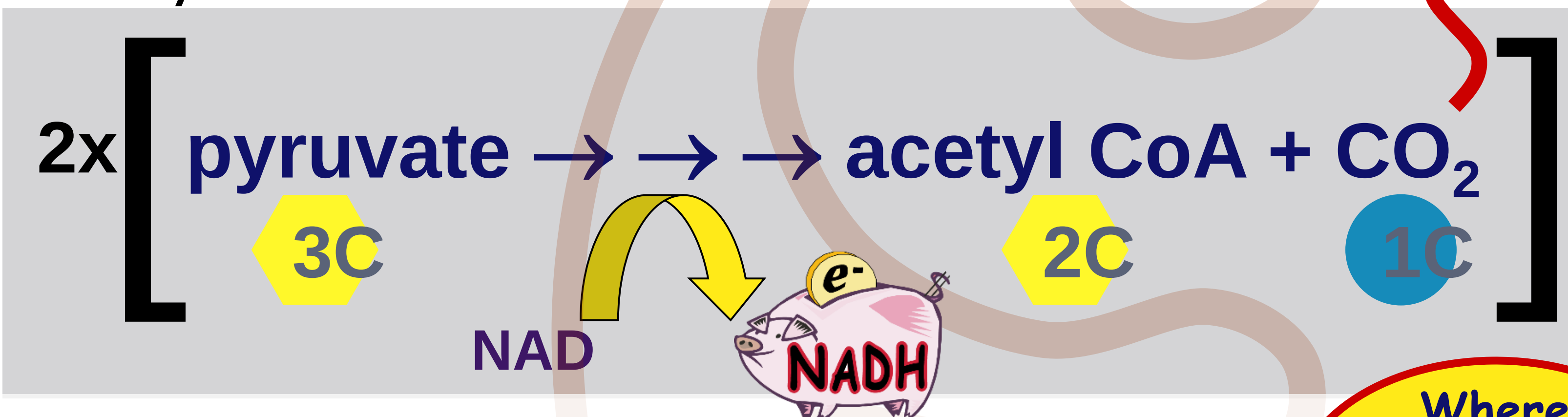
Pyruvate Oxidation

- 2 Pyruvate → 2 Acetyl CoA (*used to make citrate*)
- **Produces: $2CO_2$ and 2NADH**

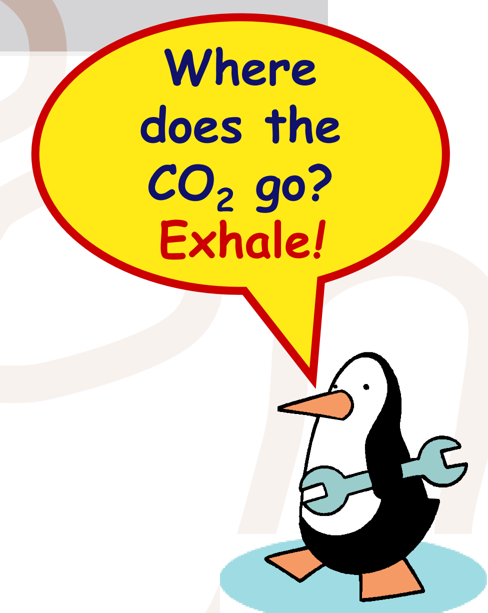


Oxidation of pyruvate

- Pyruvate enters mitochondrial matrix



  - 3 step oxidation process
  - releases 2 CO_2 (count the carbons!)
  - reduces 2 NAD → 2 NADH (moves e^-)
  - produces 2 acetyl CoA
- Acetyl CoA enters Krebs cycle



Krebs cycle

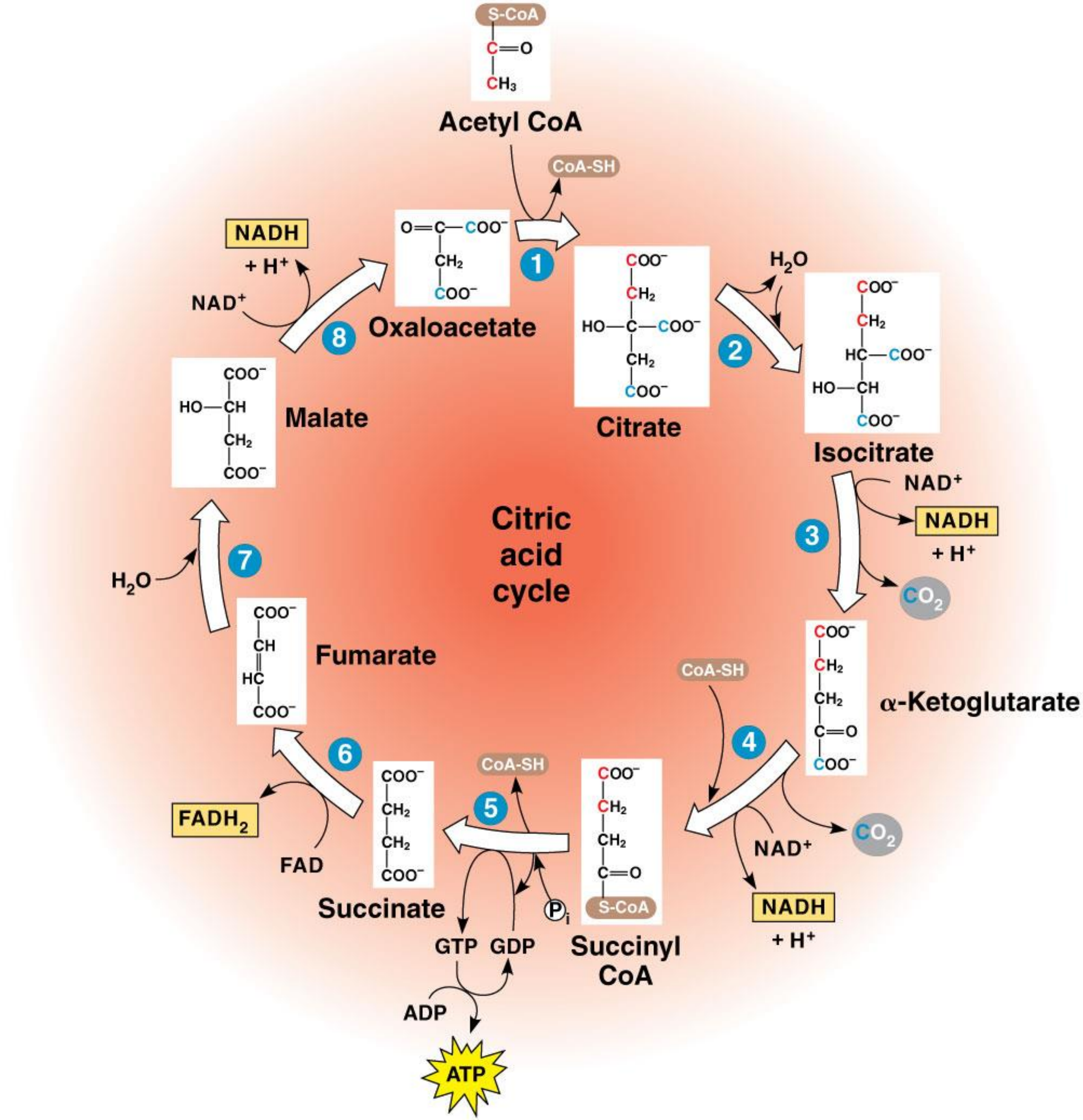
1937 1953

Hans Krebs
1900-1981

- aka Citric Acid Cycle
  - in mitochondrial matrix
  - 8 step pathway
    - each catalyzed by specific enzyme
    - step-wise catabolism of 6C citrate molecule
- Evolved later than glycolysis
  - does that make evolutionary sense?
    - bacteria →3.5 billion years ago (glycolysis)
    - free O_2 →2.7 billion years ago (photosynthesis)
    - eukaryotes →1.5 billion years ago (aerobic respiration = organelles → mitochondria)

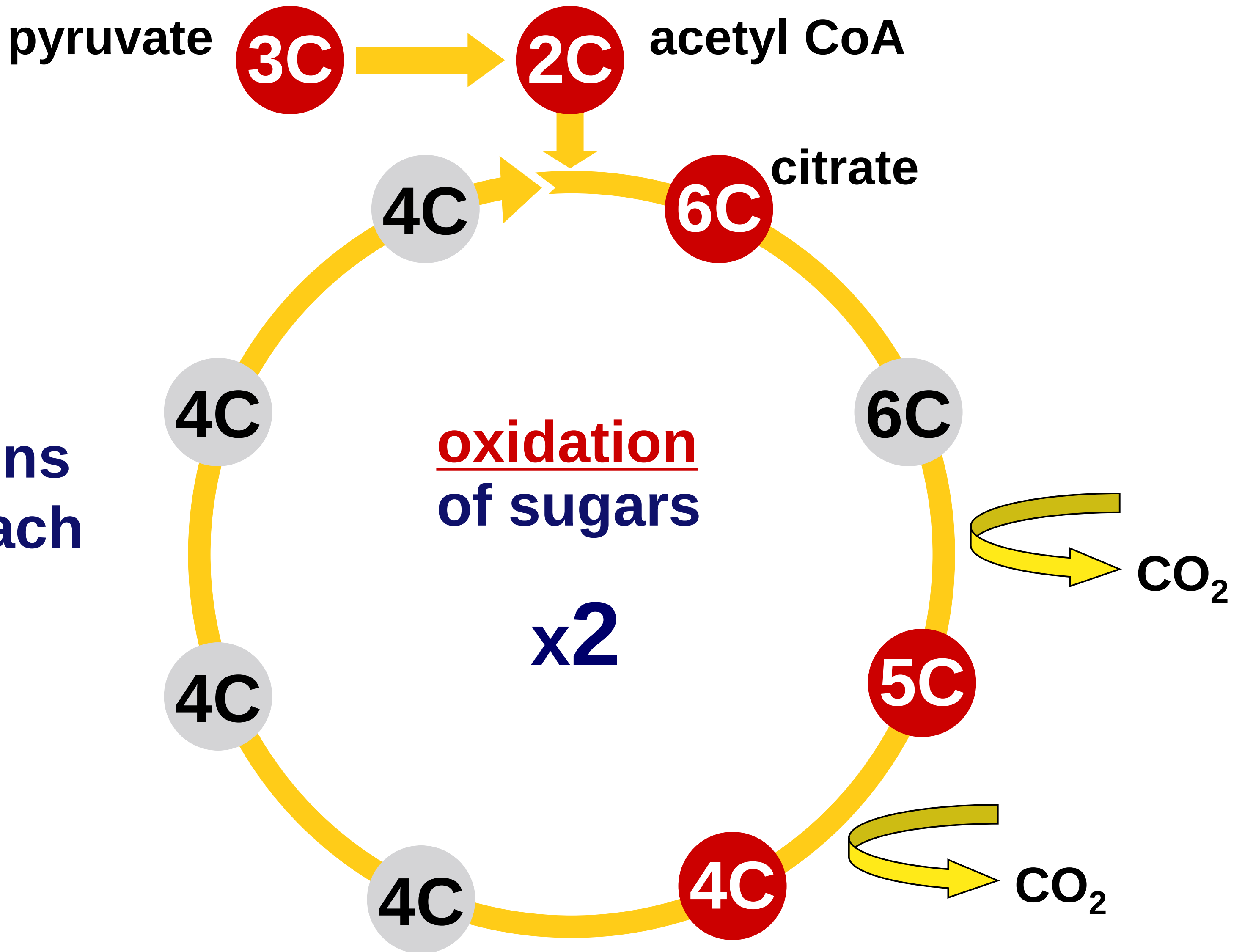
Citric Acid Cycle (Krebs)

- **Location**: Occurs in mitochondrial matrix
- **Reaction**:
  - Acetyl CoA → Citrate → CO_2 released
- **Net Yield**:
  - **2 ATP**, **6 NADH**, **2 $FADH_2$** (electron carrier)
  - **ATP** produced by <u>substrate-level phosphorylation</u>



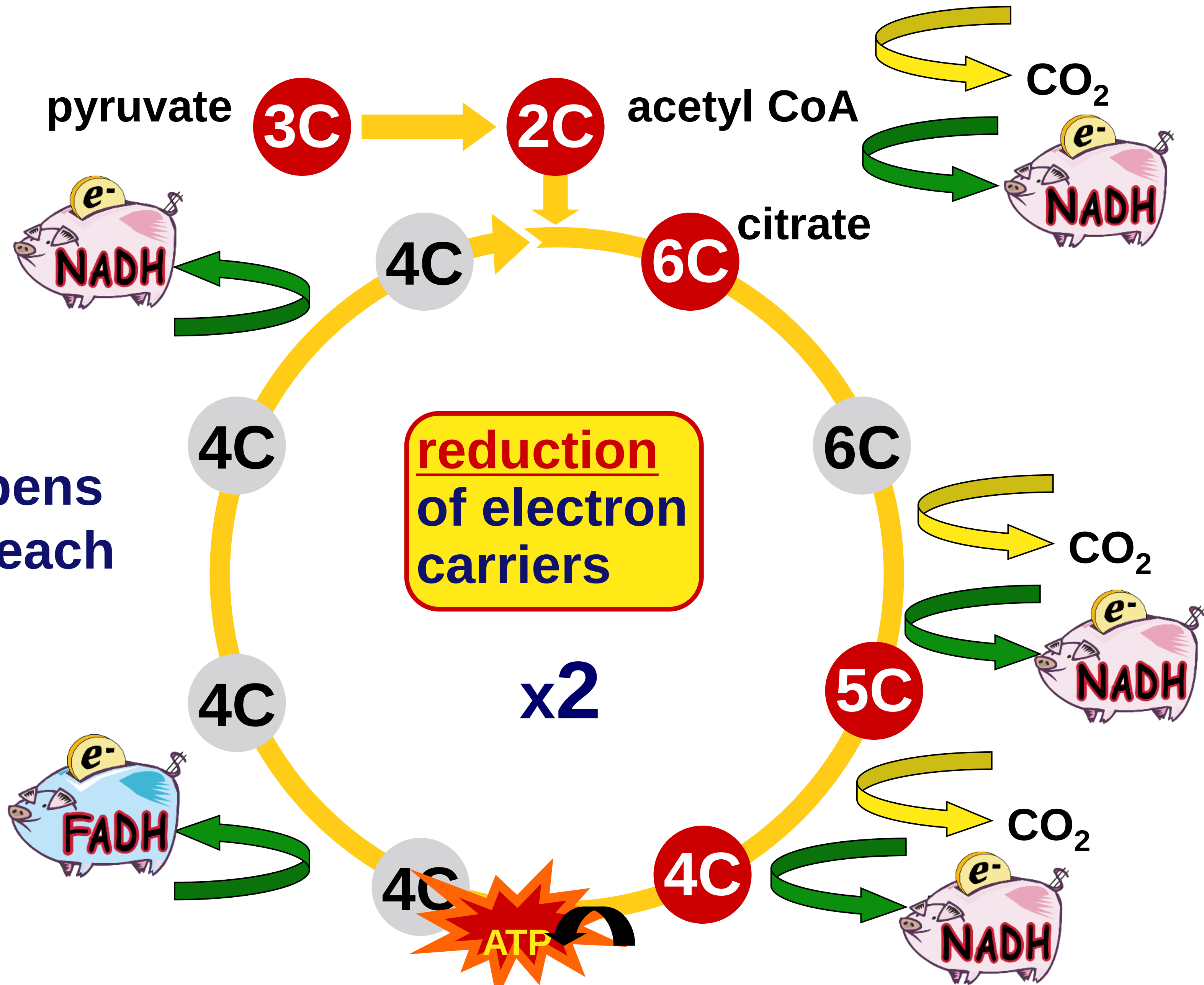
S-CoA
Acetyl CoA
CoA-SH
1
Citrate
H_2O
2
Isocitrate
NAD^+
NADH
$+ H^+$
3
CO_2
α-Ketoglutarate
CoA-SH
4
CO_2
NAD^+
NADH
$+ H^+$
Succinyl CoA
S-CoA
CoA-SH
5
P_i
GTP GDP
ADP
ATP
Succinate
6
FAD
$FADH_2$
Fumarate
7
H_2O
Malate
8
NAD^+
NADH
$+ H^+$
Oxaloacetate
Citric acid cycle

Count the carbons!



This happens **twice** for each glucose molecule

Count the electron carriers!



This happens twice for each glucose molecule

Whassup?

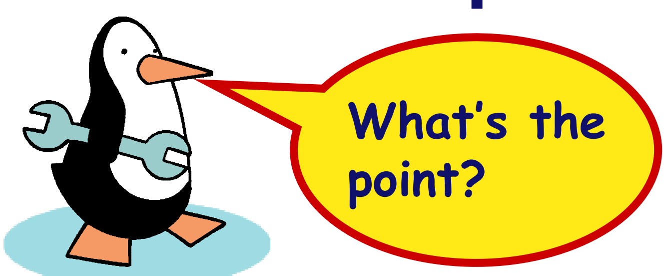
So through Glycolysis, Pyruvate Oxidation, and the Krebs Cycle, we fully oxidized glucose

$$C_6H_{12}O_6$$

$$\downarrow$$

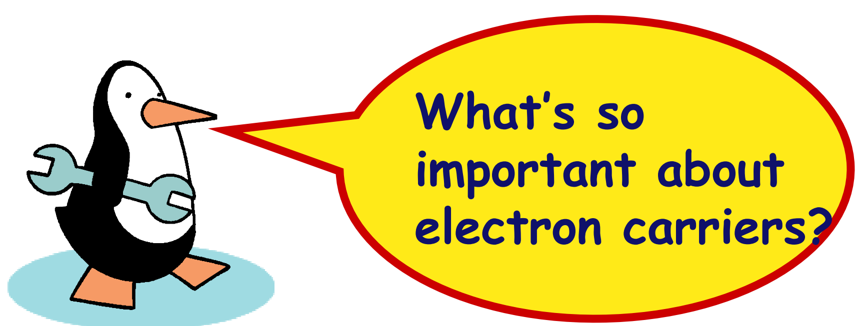
$$CO_2$$

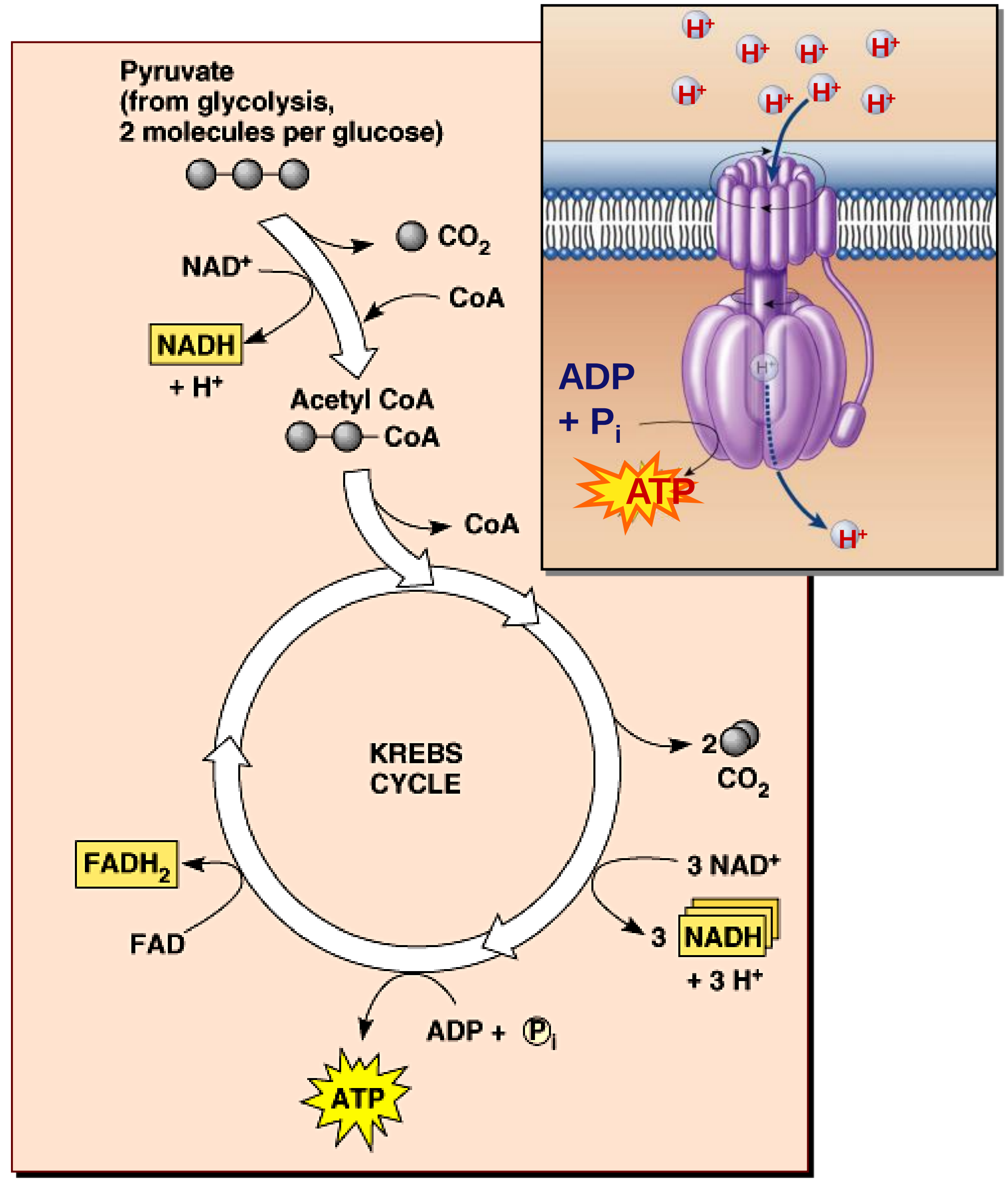
& ended up with 4 ATP*!*



Electron Carriers = Hydrogen Carriers

- **Krebs cycle produces large quantities of <u>electron carriers</u>**
  - **NADH**
  - **$FADH_2$**
  - **go to <u>Electron Transport Chain!</u>**





Value of Krebs cycle?

- If the yield is only 2 ATP then how was the Krebs cycle an adaptation?
  - value of NADH & $FADH_2$
    - electron carriers & H carriers
      - reduced molecules move electrons
      - reduced molecules move H^+ ions
    - to be used in the Electron Transport Chain

REVIEW: TURN & TALK

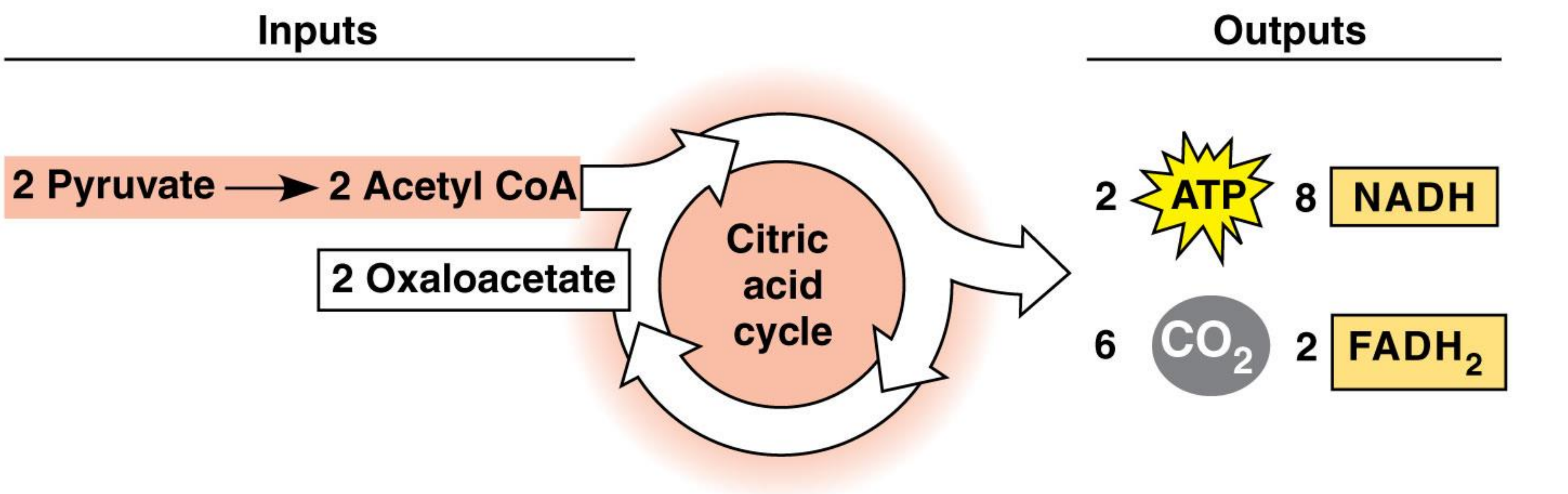
1. Explain "glycolysis". Where does it occur? How does it "work"?

2. What is the overall chemical equation for cellular respiration?

3. Which has more energy available:
   a. ADP or ATP?
   b. NAD^+ or NADH?
   c. FAD^+ or $FADH_2$?

4. Where does the Citric Acid Cycle occur in the cell?

Summary of Citric Acid Cycle



Now take 5 minutes and write a PARAGRAPH summary of Krebs Cycle in your notes.

POGIL: Model 2-3 Link & Krebs Cycle

- Work through Models 2 & 3.
- STOP before Oxidative Phosphorylation

HOMEWORK

1. Watch the video "Cellular Respiration" from Bozeman Science http://www.bozemanscience.com/cellular-respiration

2. Take Cornell notes
    1. You may use diagrams for notes!
    2. Show questions on left side
    3. Write a summary at the end

Topic: Cellular Respiration (*Bozeman Science*)

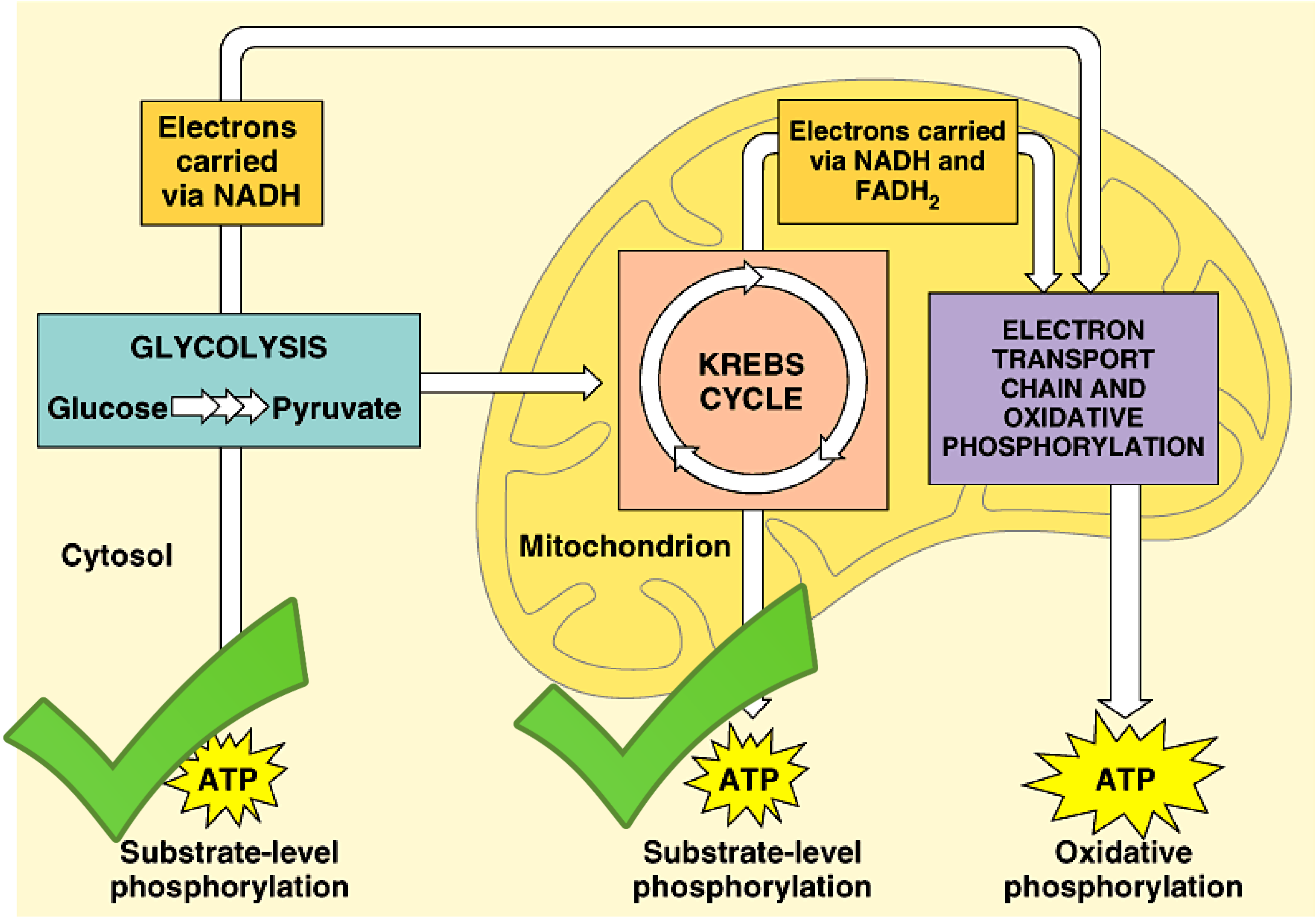
Questions/ Key Ideas	Notes/Drawings:

Summary:

Cellular Respiration

Stage 3: Oxidative Phosphorylation

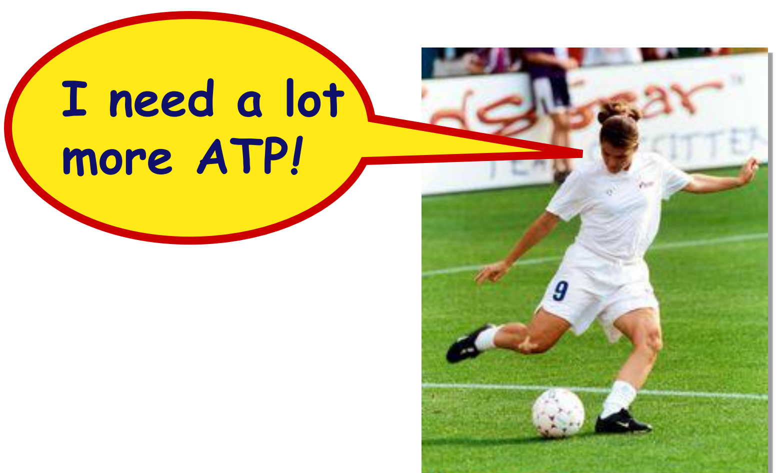
Cellular respiration

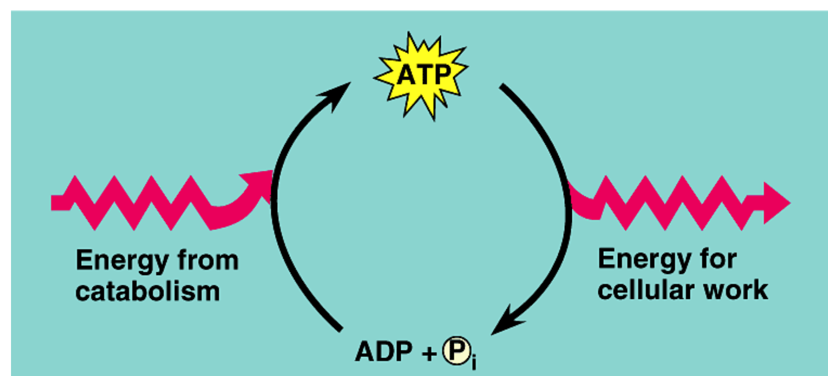


ATP accounting so far…

- Glycolysis → 2 ATP
- Kreb's cycle → 2 ATP
- Life takes a lot of energy to run, need to extract more energy than 4 ATP!

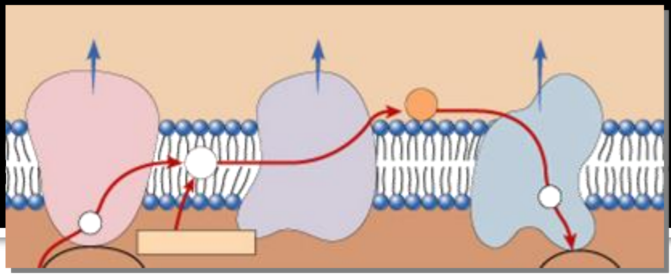
There's got to be a better way!





A working muscle recycles over 10 million ATPs per second

There *is* a better way!



- Electron Transport Chain
  - series of proteins built into inner mitochondrial membrane
    - along cristae
    - transport proteins & enzymes
  - transport of electrons down ETC linked to pumping of H^+ to create H^+ gradient
  - yields ~36 ATP from 1 glucose*!*
  - only in presence of O_2 (aerobic respiration)

Oxidative Phosphorylation

ELECTRON TRANSPORT CHAIN

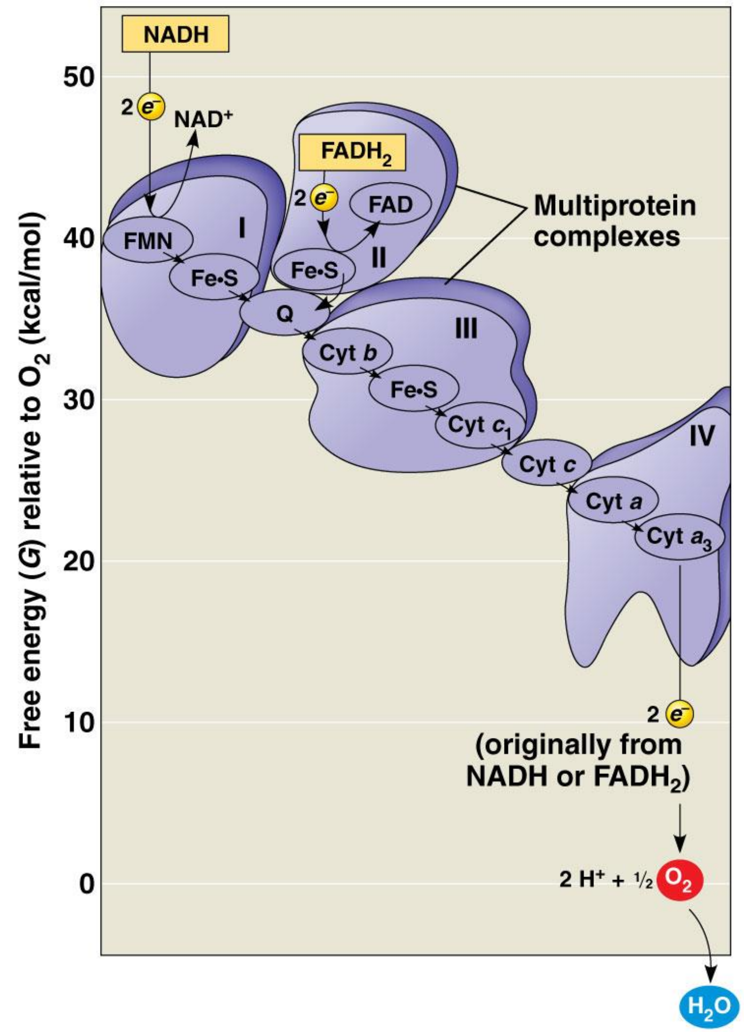
- Occurs in inner membrane of mitochondria
- Produces **26-28 ATP** by oxidative phosphorylation via chemiosmosis

CHEMIOSMOSIS

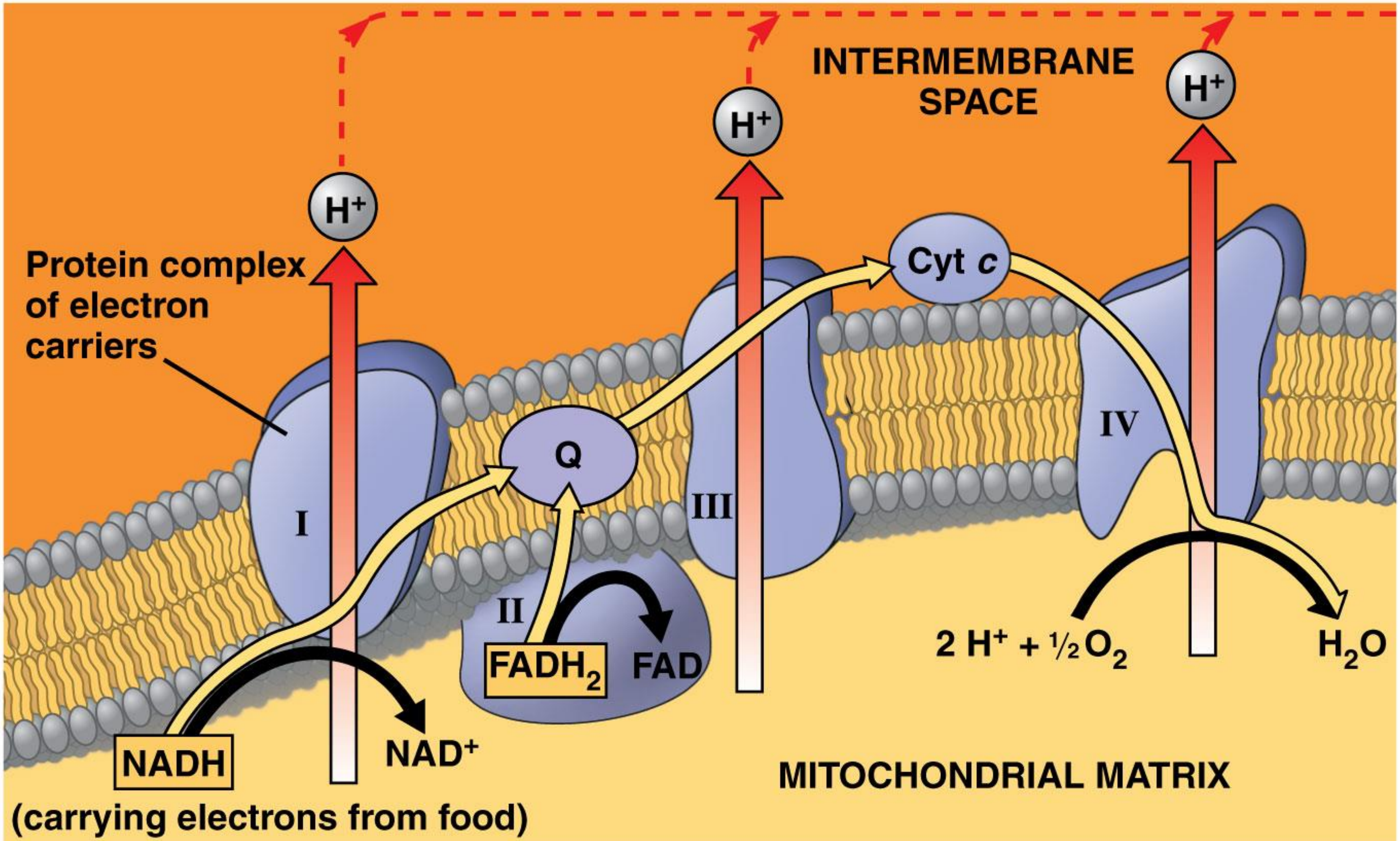
- H^+ ions (protons) pumped across inner mitochondrial membrane
- H^+ diffuse through ATP synthase (ADP → ATP)

Electron Transport Chain (ETC)

- A collection of molecules embedded in inner membrane of mitochondria
- Tightly bound protein & non-protein components
- Alternate between reduced/oxidized states as accept/donate e^-
- Does <u>not</u> make ATP directly
- Controls the fall of e- from food to O_2
- $2H^+ + \frac{1}{2} O_2 \rightarrow$ **H_2O at end**

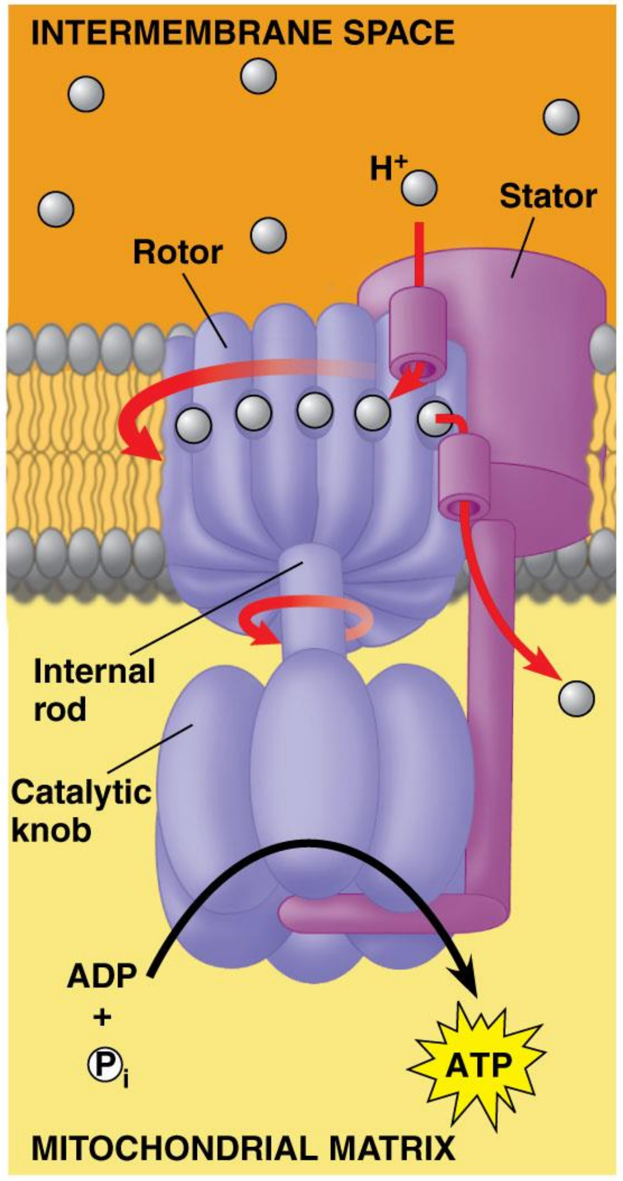


As electrons move through the ETC, proton pumps move H^+ across inner mitochondrial membrane



CHEMIOSMOSIS: Energy-Coupling Mechanism

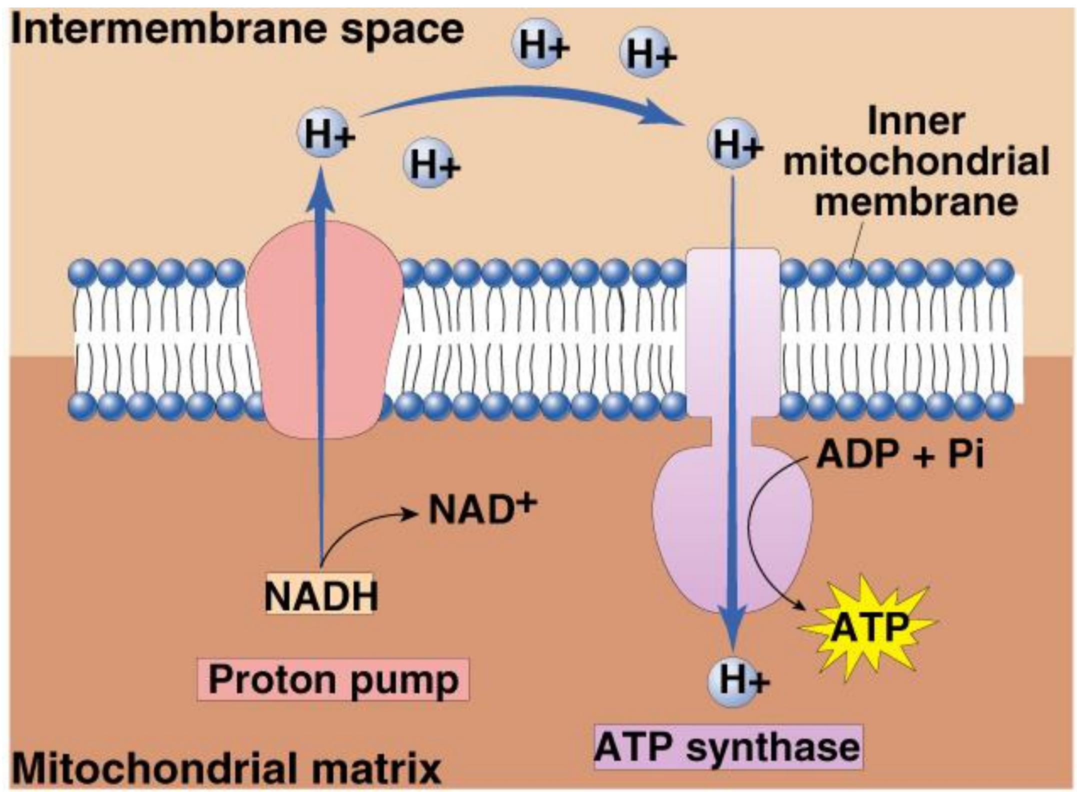
- **Chemiosmosis** = H^+ gradient across membrane that drives cellular work
- **Proton-motive force**: use proton (H^+) gradient to perform work
- **ATP synthase**: enzyme that makes ATP
- Use E from proton (H^+) gradient – flow of H^+ back across membrane



Chemiosmosis

- The diffusion of ions across a membrane
  - build up of proton gradient just so H+ could flow through ATP synthase enzyme to build ATP

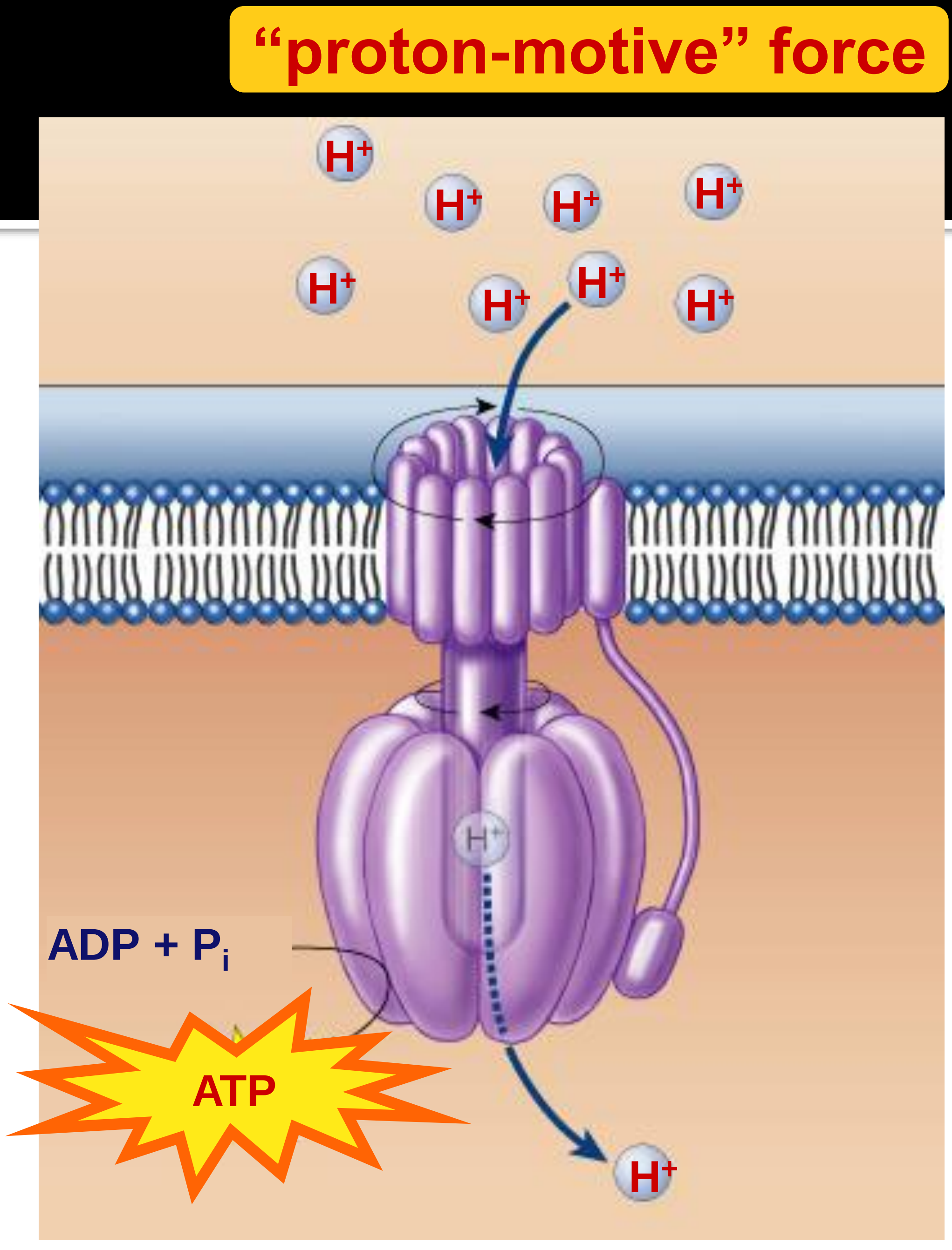
Chemiosmosis links the Electron Transport Chain to ATP synthesis



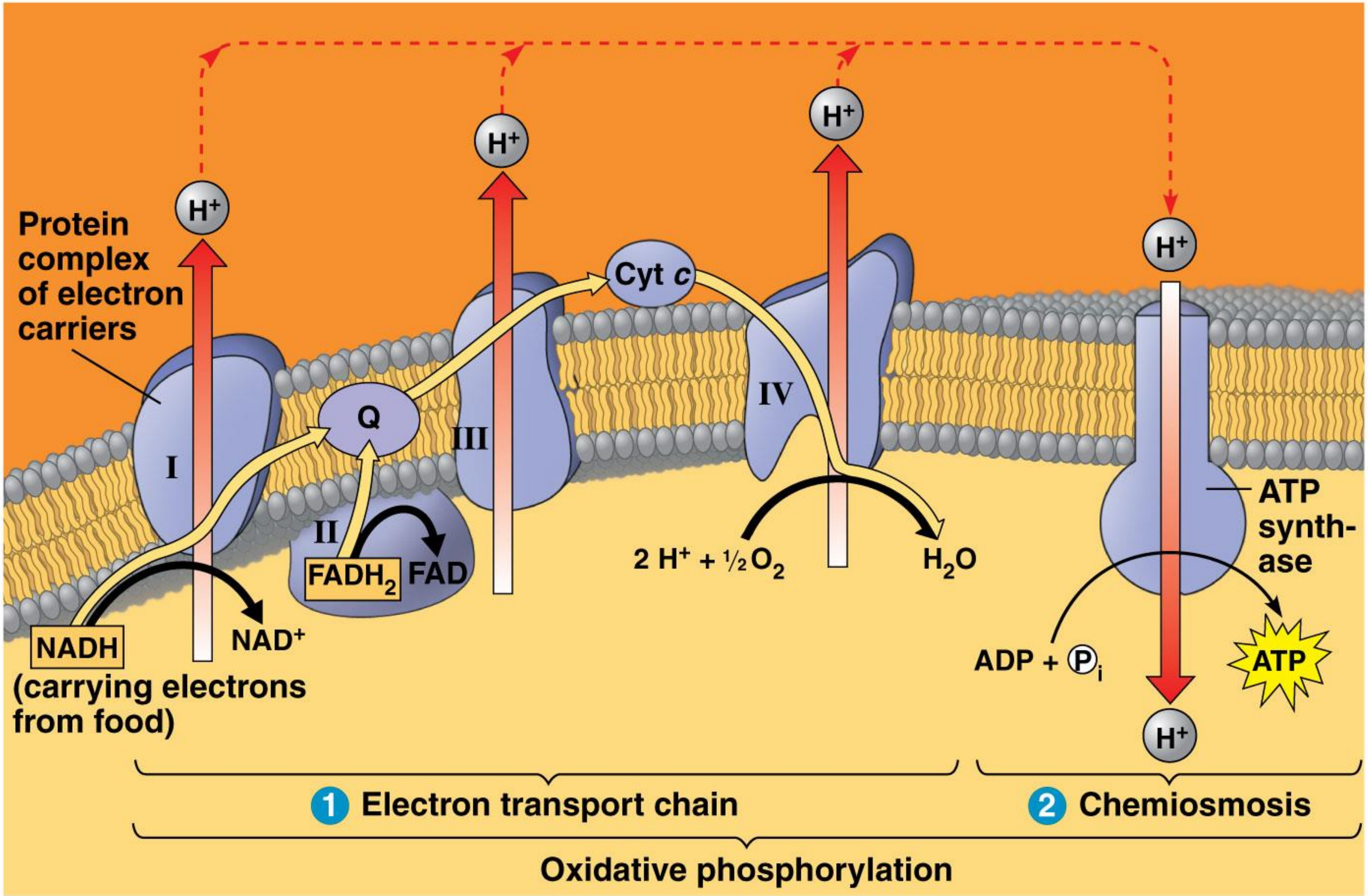
Chemiosmosis

- Set up a H^+ gradient
- Allow the <u>protons</u> to flow through ATP synthase
- Synthesizes ATP

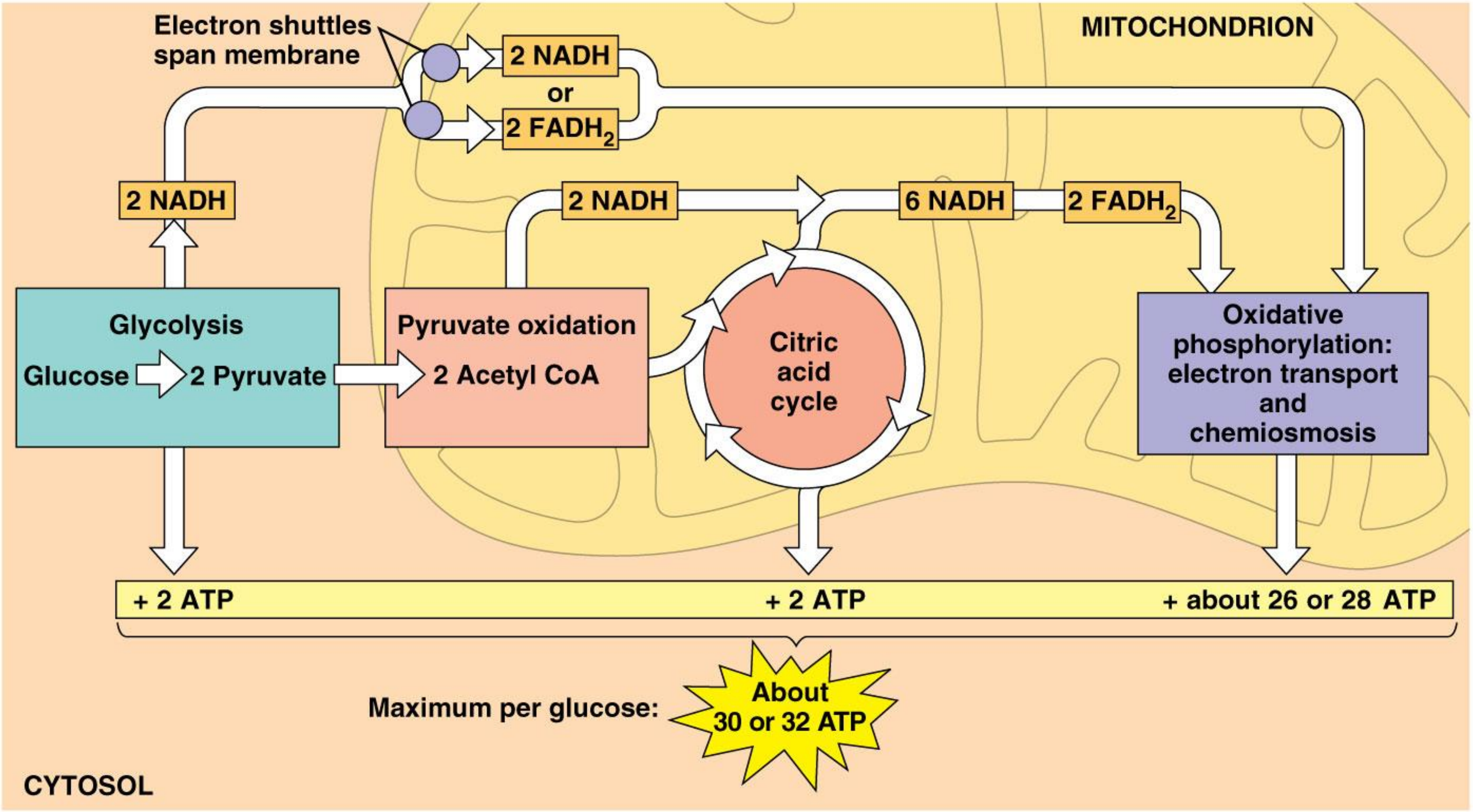
$ADP + P_i \rightarrow ATP$

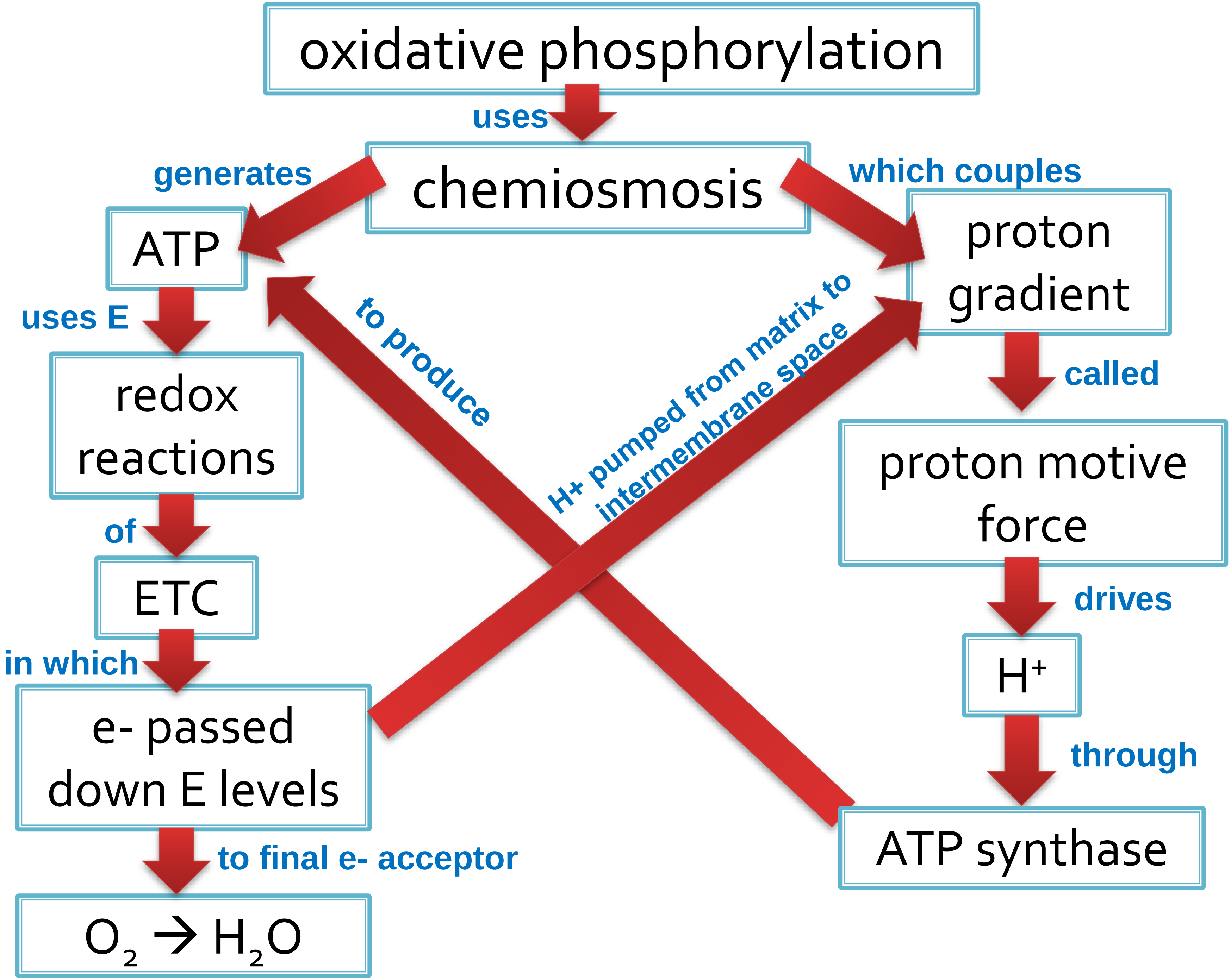


Chemiosmosis couples the ETC to ATP synthesis



ATP yield per molecule of glucose at each stage of cellular respiration




oxidative phosphorylation
uses
chemiosmosis
generates
ATP
which couples
proton gradient
uses E
redox reactions
to produce
H+ pumped from matrix to intermembrane space
called
proton motive force
of
ETC
drives
H^+
in which
e- passed down E levels
through
ATP synthase
to final e- acceptor
$O_2 \rightarrow H_2O$

POGIL: Oxidative Phosphorylation

- Work through Model 4

You may choose which paper to turn in from your group!

Write FIRST & LAST names on one paper (or sticky note) and turn in to the tray.

Happy Friday!

- EVERYONE: Use your notes (but NOT your neighbors) to complete the warm-up today.
- 4^{TH} BLOCK: Staple your Final Lab Report on the top of your Enzyme Lab Packet. Turn in to the tray!

POGIL: Oxidative Phosphorylation

- Finish up the POGIL from yesterday

You may choose which paper to turn in from your group!

Write FIRST & LAST names on one paper (or sticky note) and turn in to the tray.

https://www.youtube.com/watch?v=7J4LXs-0DCU

Cellular Respiration Glycolysis, Krebs cycle, Electron Transport 3D Animation

Anaerobic Cellular Respiration

Aerobes vs Anaerobes

New Handout

1. What are obligate aerobes?
2. What are obligate anaerobes?
3. What are facultative anaerobes?

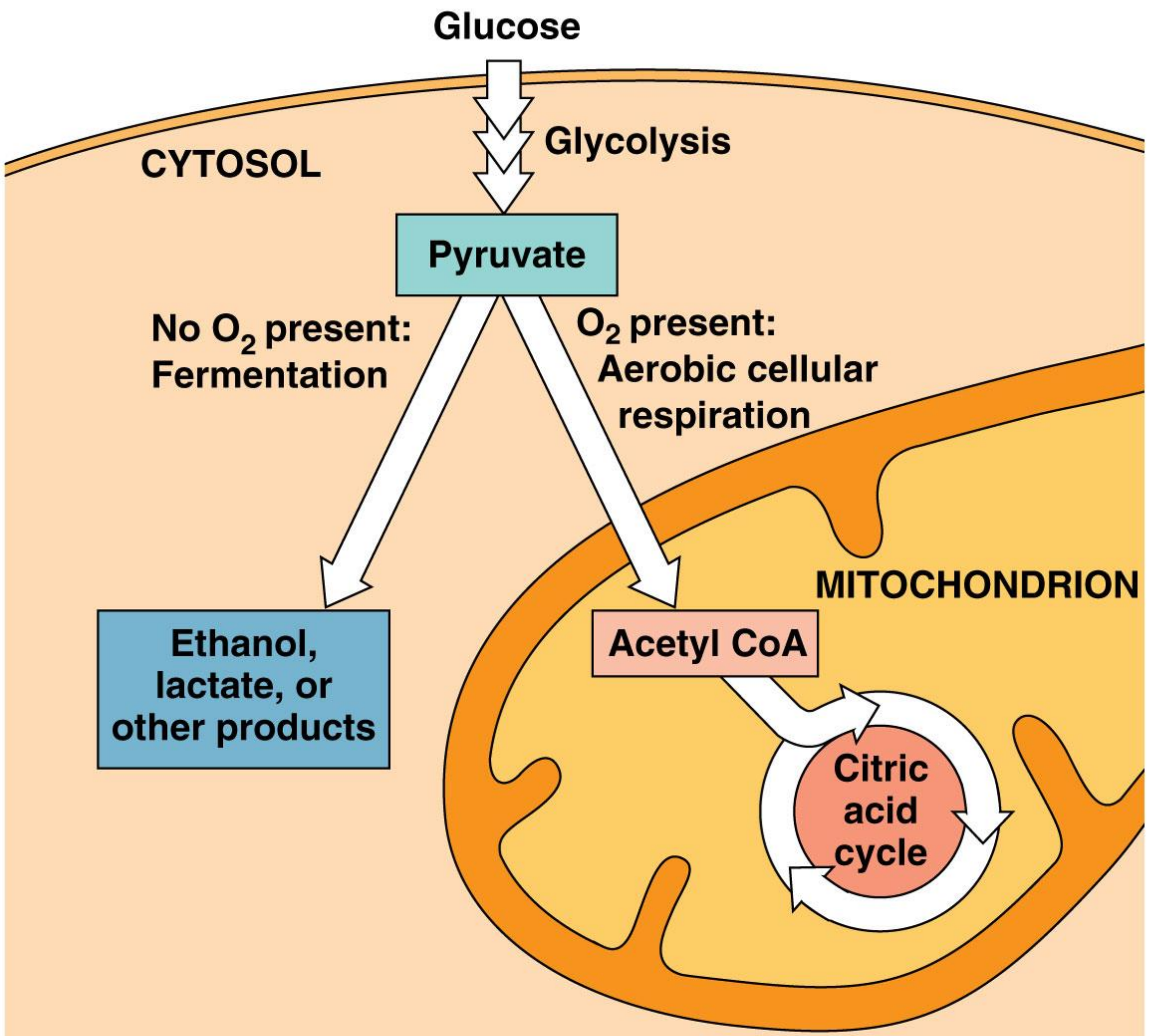
- What kind of environment can they live in?
- What kind of environment *can't* they live in?

- **Anaerobic Respiration**: generate ATP using other electron acceptors besides O_2
  - Final e^- acceptors: sulfate (SO_4), nitrate, sulfur (produces H_2S)

- **Obligate anaerobes**: Can't survive in o_2

- **Facultative anaerobes**: make ATP by **aerobic respiration** (with O_2 present) *or switch* to **fermentation** (when no O_2 available)
  - Eg. human muscle cells

Fermentation = glycolysis + regeneration of NAD^+



Glycolysis

Without O_2 | O_2 present

FERMENTATION

- Keep glycolysis going by regenerating NAD^+
- Occurs in cytosol
- **No oxygen** needed
- Creates **ethanol** [+ CO_2] or **lactate**
- **2 ATP** (from glycolysis)

RESPIRATION

- Release E from breakdown of food with O_2
- Occurs in mitochondria
- **O_2 required** (final electron acceptor)
- Produces CO_2, H_2O and **up to 32 ATP**

Types of Fermentation

ALCOHOL FERMENTATION

- Pyruvate → Ethanol + CO_2
- Ex. bacteria, yeast
- Used in brewing, winemaking, baking

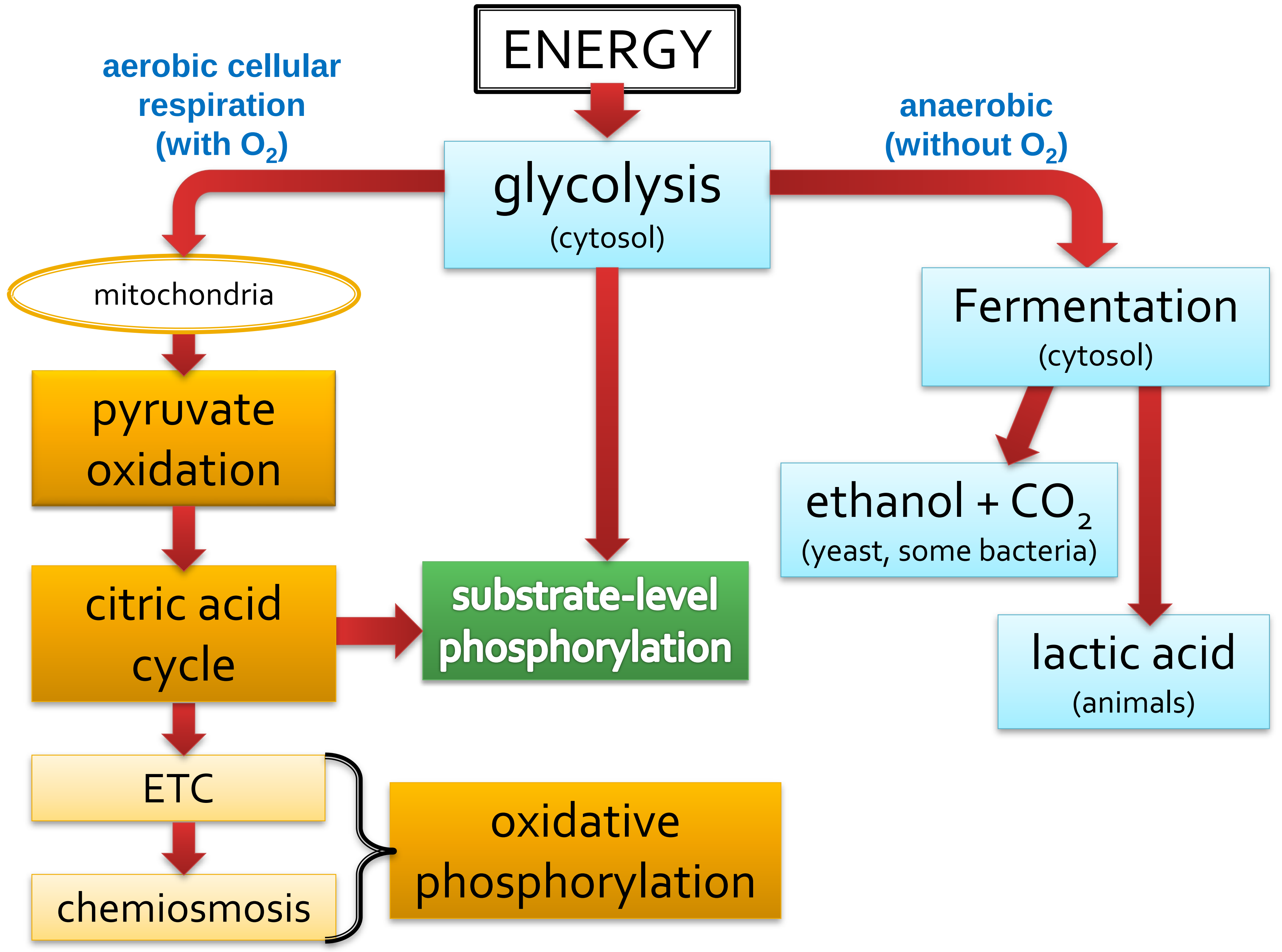
LACTIC ACID FERMENTATION

- Pyruvate → Lactate
- Ex. fungi, bacteria, human muscle cells
- Used to make cheese, yogurt, acetone, methanol
- Note: Lactate build-up does NOT causes muscle fatigue and pain (old idea)

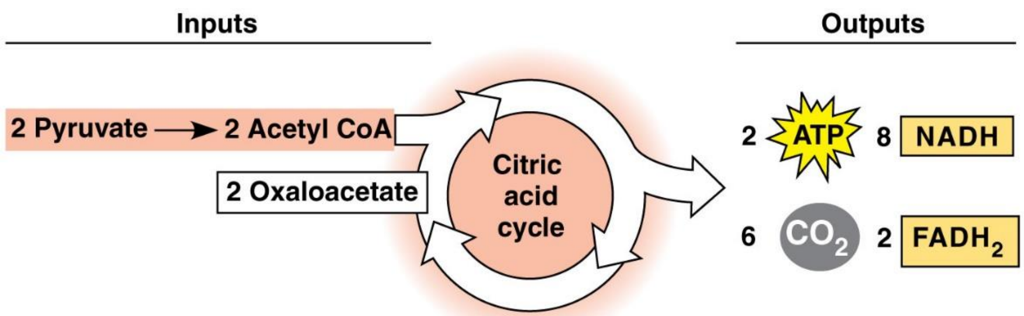
Did you know?

- **Plants can** also respire **anaerobically**, which **can** be extremely useful when their roots become completely waterlogged (and thus unable to access oxygen). **Plants anaerobically** respire by ethanol fermentation in the same way that yeast respires when making alcohol and bread.

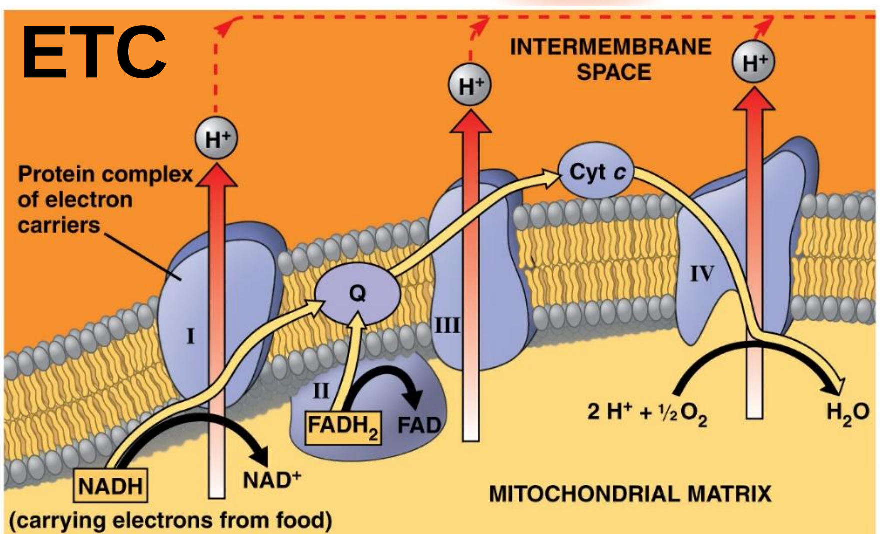
Respiration: Big Picture


ENERGY
aerobic cellular respiration (with O_2)
anaerobic (without O_2)
glycolysis
(cytosol)
mitochondria
pyruvate oxidation
citric acid cycle
substrate-level phosphorylation
Fermentation
(cytosol)
ethanol + CO_2
(yeast, some bacteria)
lactic acid
(animals)
ETC
chemiosmosis
oxidative phosphorylation

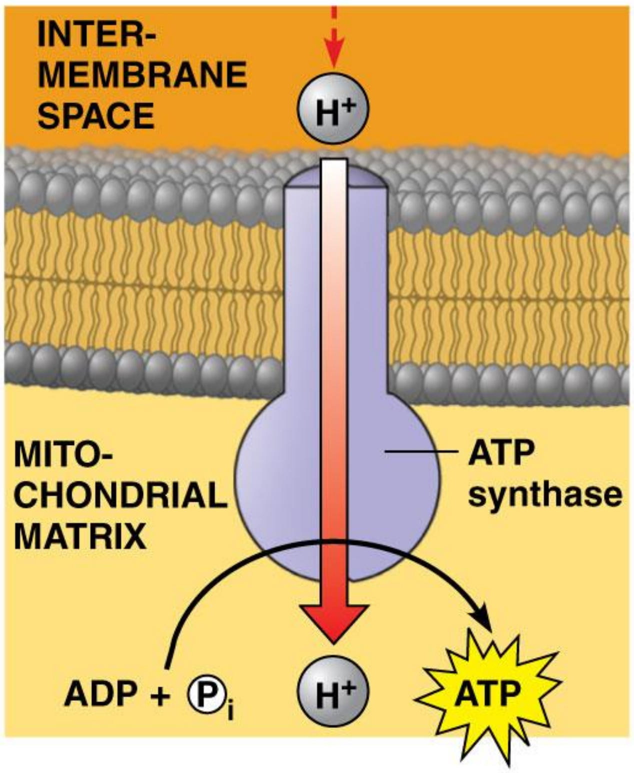
Write your Summary of Cellular Respiration



ETC



Chemiosmosis



Cellular Energetics Trick-or-Treat

1. Take a sentence strip. Use your notes to figure out what word goes in the blank. (Do NOT write on it, though)

2. Read it <u>OUT LOUD</u> to the class.

3. Get a piece of candy if you're correct!

What's the Difference?

SUBSTRATE-LEVEL PHOSPHORYLATION

- Add P_i from one compound (substrate) to ADP *directly*
- Energy comes from the chemical reaction itself
- "no middle man"
- Uses:
  - Glycolysis
  - Krebs Cycle

OXIDATIVE PHOSPHORYLATION

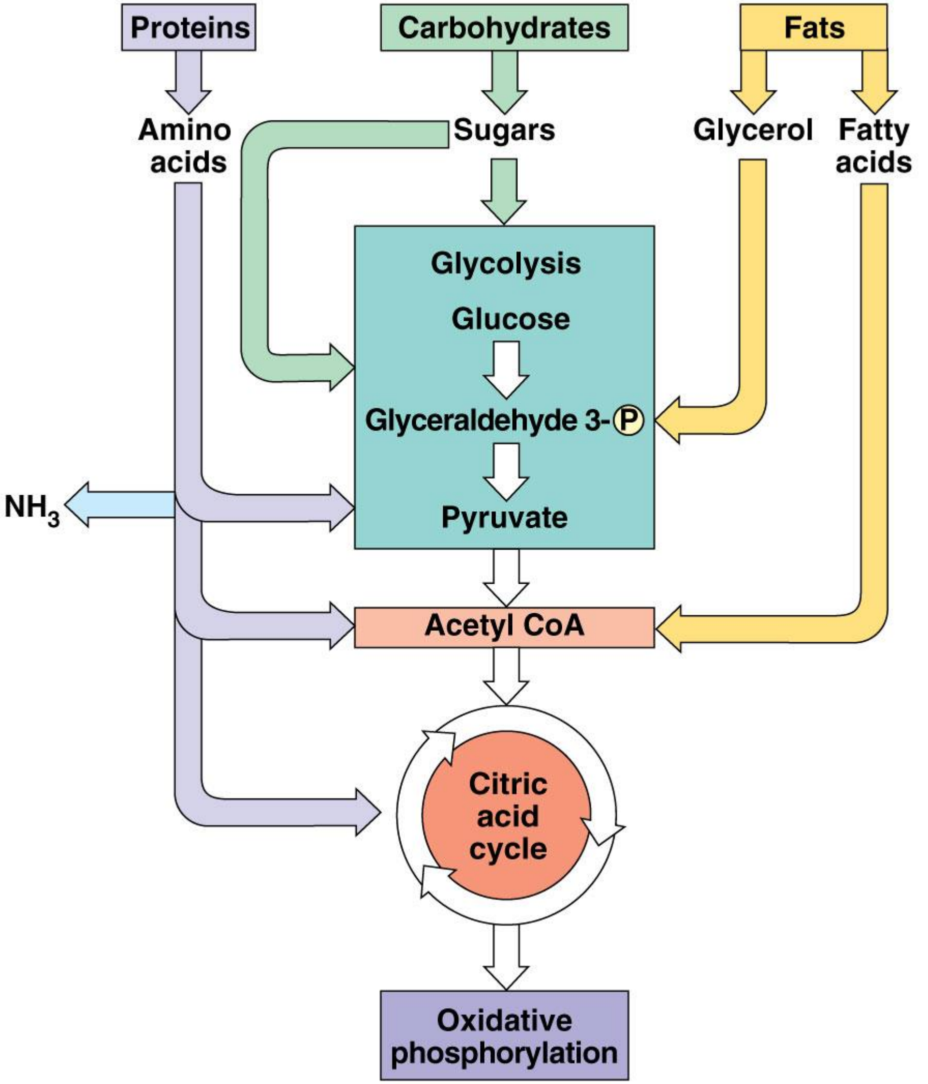
- Uses a "middle man" = NADH and FADH and the pumping of electrons to generate an electrochemical gradient to make ATP
- Pi come from a pool of phosphates
- Uses:
  - ETC + Chemiosmosis

Cellular Respiration

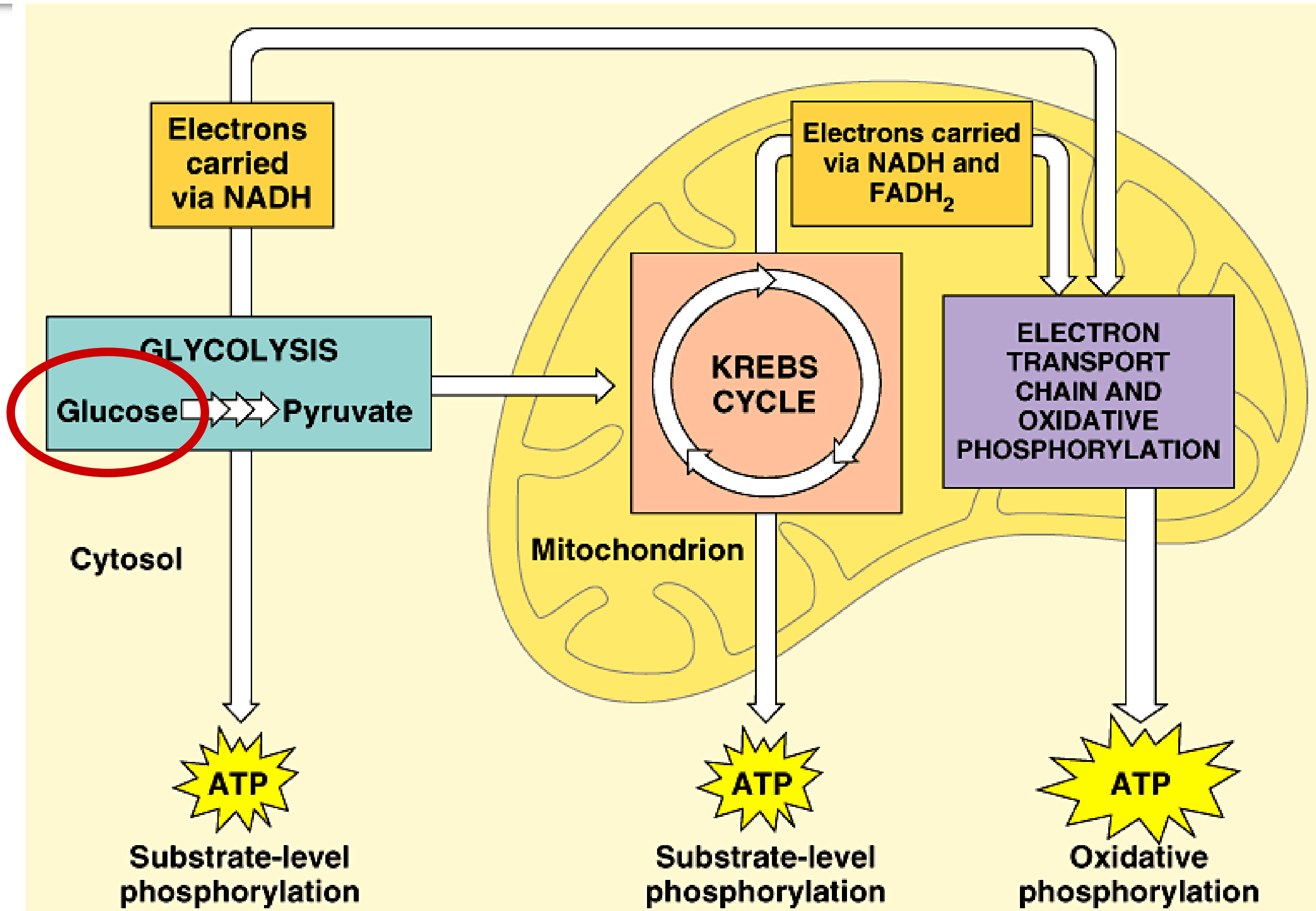
Other Metabolites & Control of Respiration

Various sources of fuel

- Carbohydrates, fats and proteins can ALL be used as fuel for cellular respiration
- Monomers enter glycolysis or citric acid cycle at different points



Cellular respiration



Beyond glucose: Other carbohydrates

- Glycolysis accepts a wide range of carbohydrates fuels

polysaccharides → → → glucose
hydrolysis

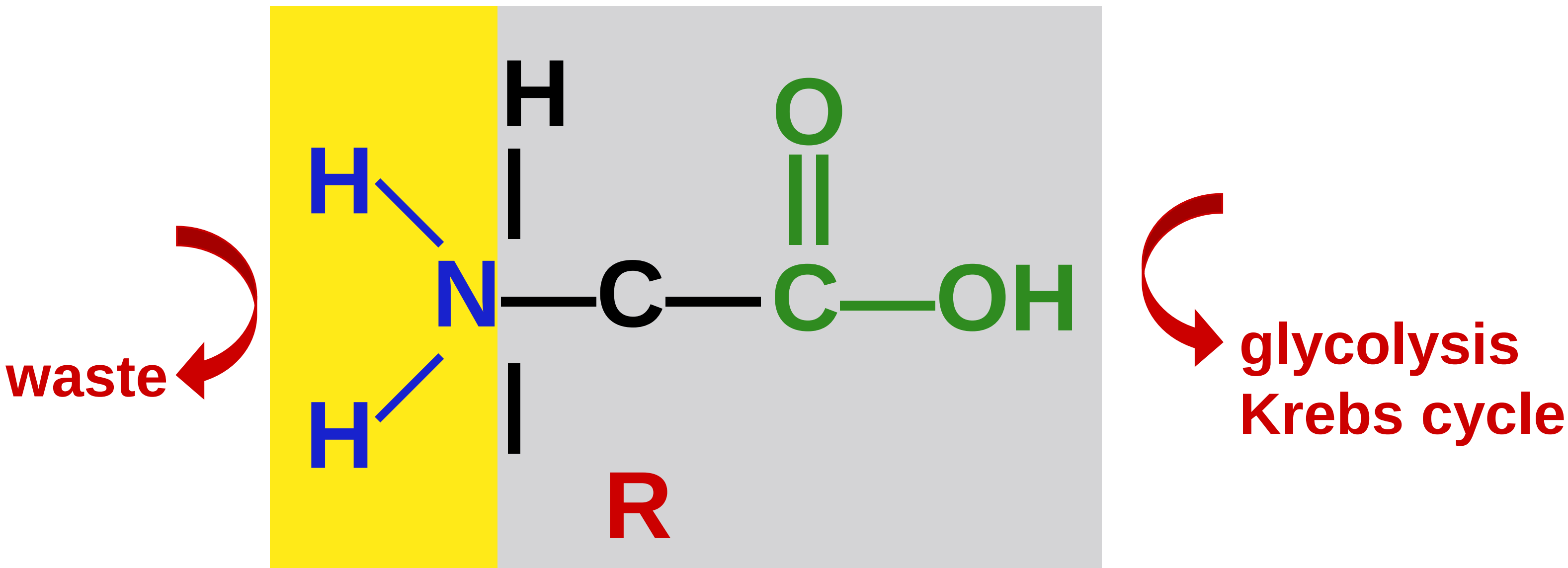
- **ex. starch, glycogen**

other 6C sugars → → → glucose
modified

- **ex. galactose, fructose**

Beyond glucose: Proteins

proteins → → → → → amino acids
hydrolysis



amino group = waste product excreted as ammonia, urea, or uric acid

2C sugar = carbon skeleton = enters glycolysis or Krebs cycle at different stages

Beyond glucose: Fats

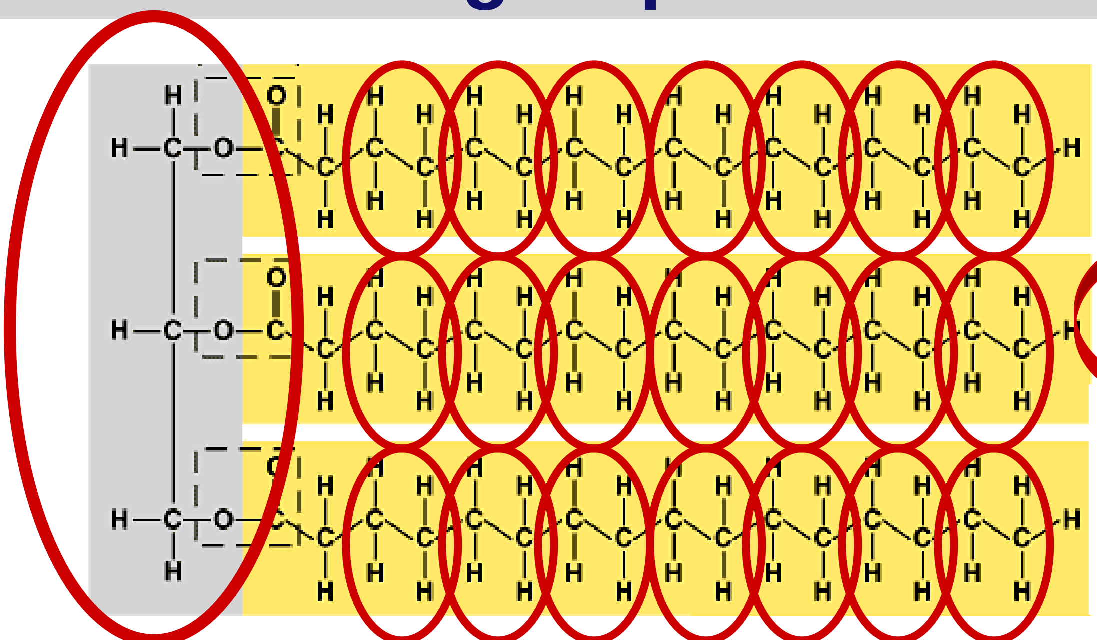
fats → → → → → glycerol + fatty acids
hydrolysis

glycerol (3C) → → G3P → → glycolysis

fatty acids → 2C acetyl groups → acetyl coA → Krebs cycle

3C glycerol

enters glycolysis as G3P



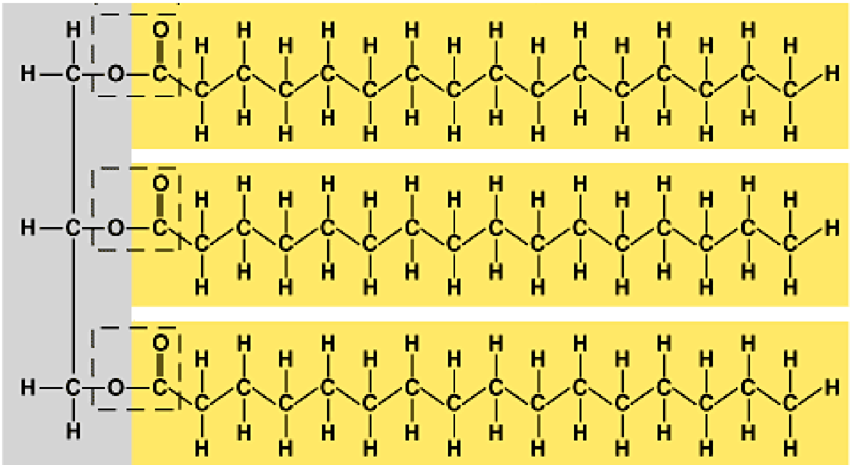
2C fatty acids

enter Krebs cycle as acetyl CoA

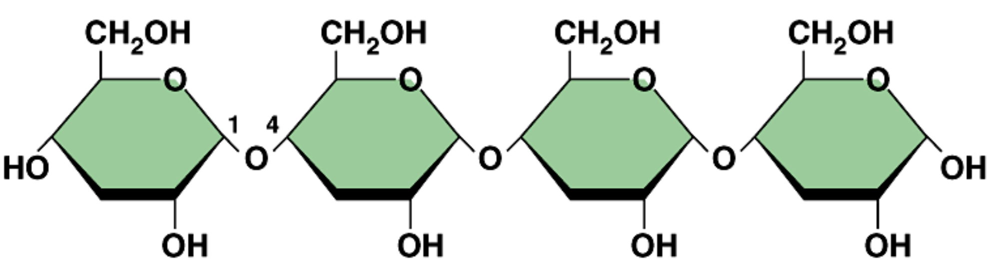
Carbohydrates vs. Fats

- Fat generates 2x ATP vs. carbohydrate
  - **more C in gram of fat**
    - more energy releasing bonds
  - **more O in gram of carbohydrate**
    - so it's already partly oxidized
    - less energy to release

fat

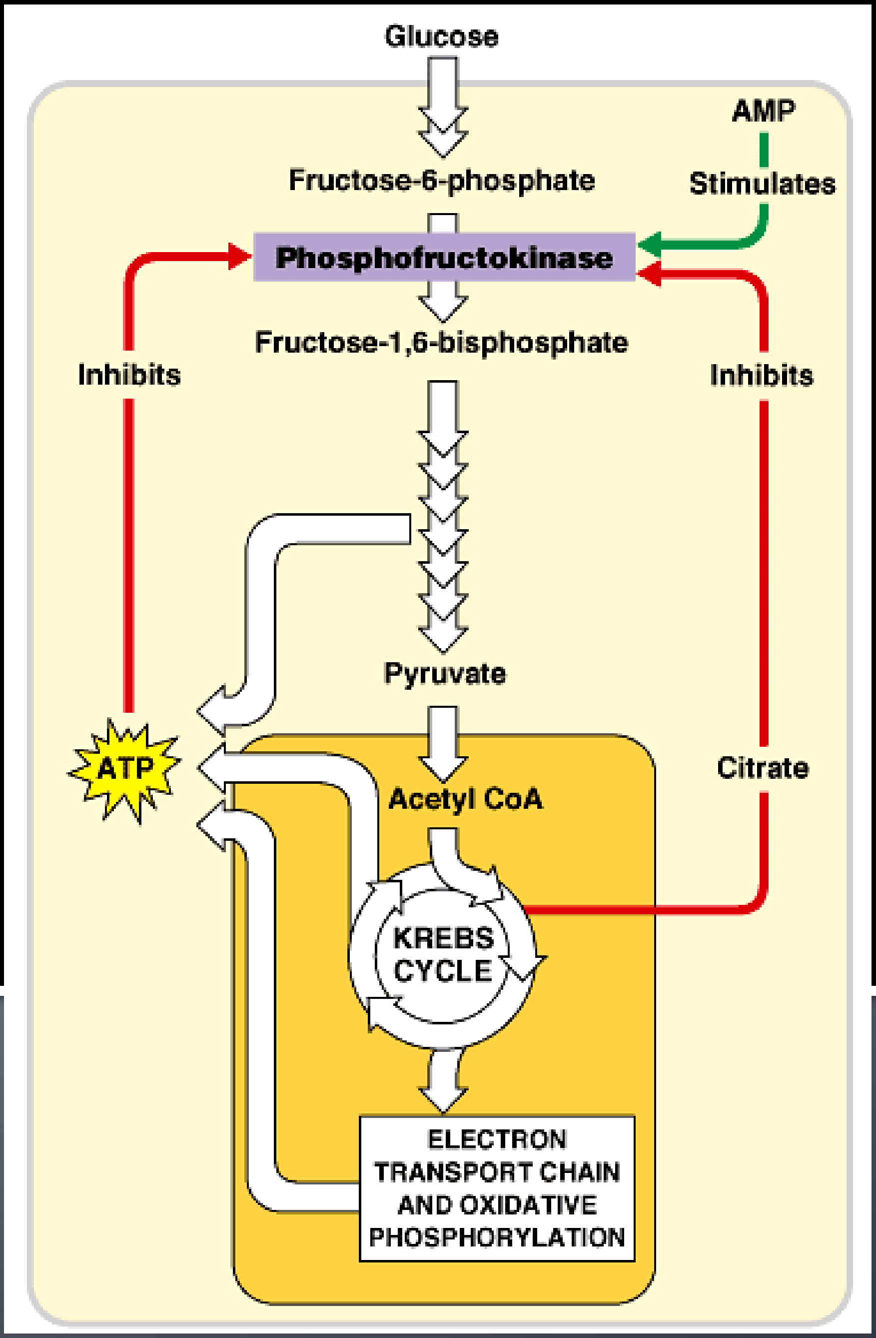


carbohydrate



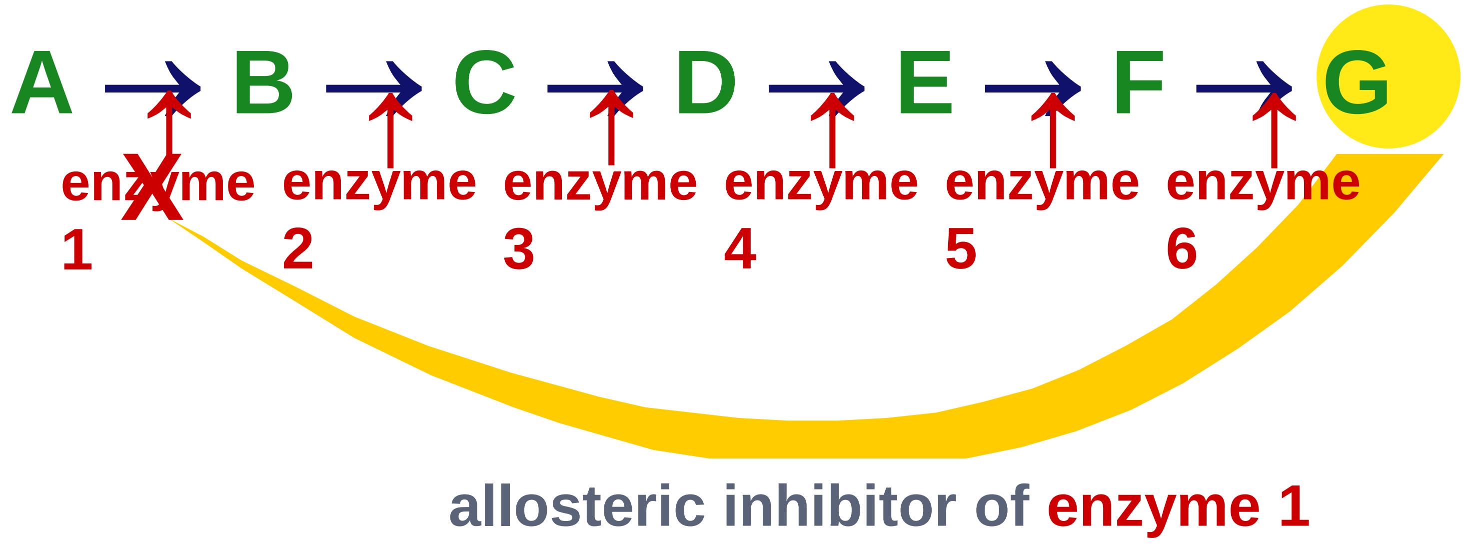
Control of Respiration

Feedback Control



Feedback Inhibition

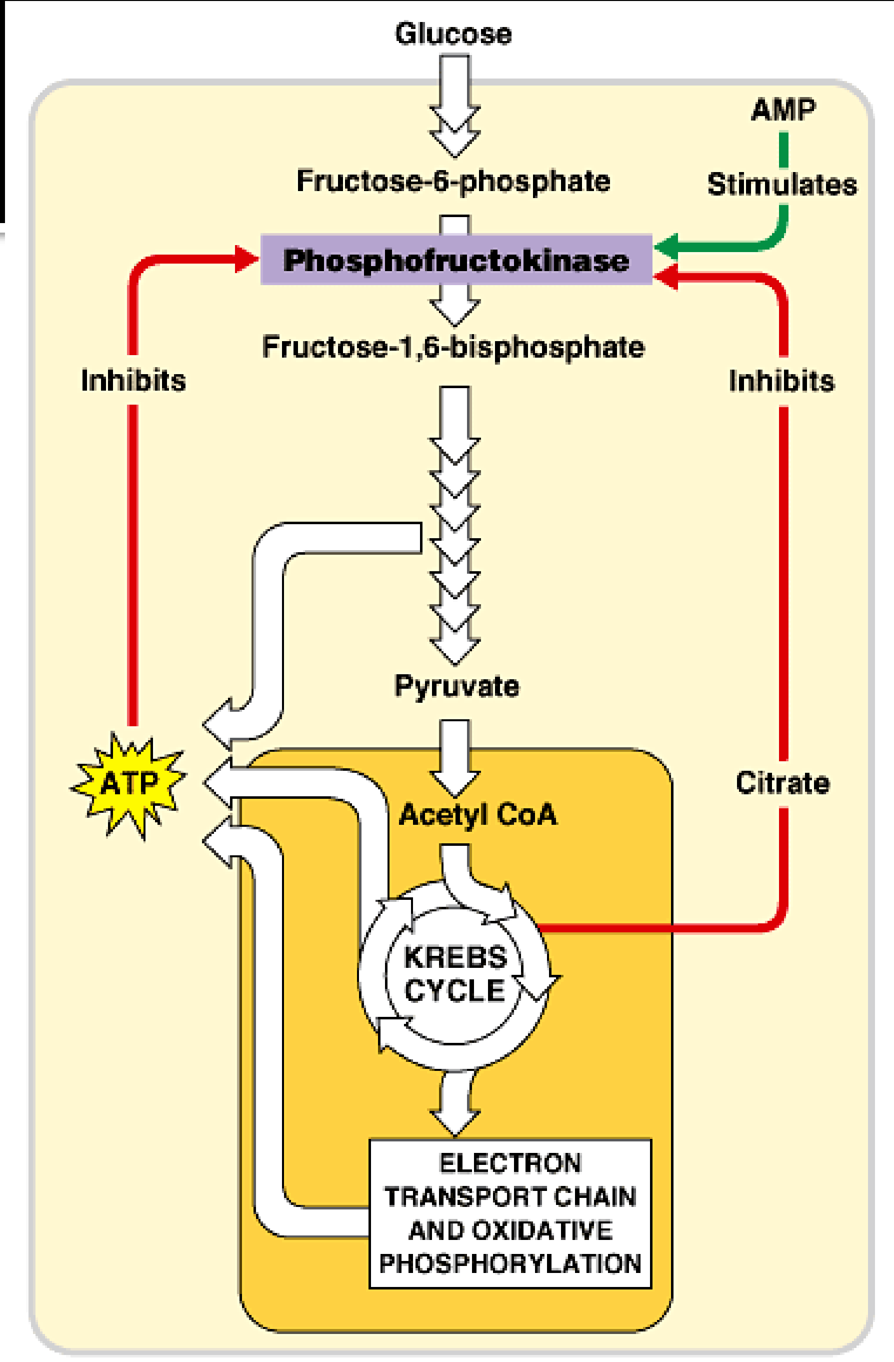
- Regulation & coordination of production
  - final product is inhibitor of earlier step
    - allosteric inhibitor of earlier enzyme
  - no unnecessary accumulation of product
  - production is self-limiting



Respond to cell's needs

- Key point of control
  - phosphofructokinase
    - allosteric regulation of enzyme
      - why here?

        "can't turn back" step before splitting glucose
    - AMP & ADP stimulate
    - ATP inhibits
    - citrate inhibits

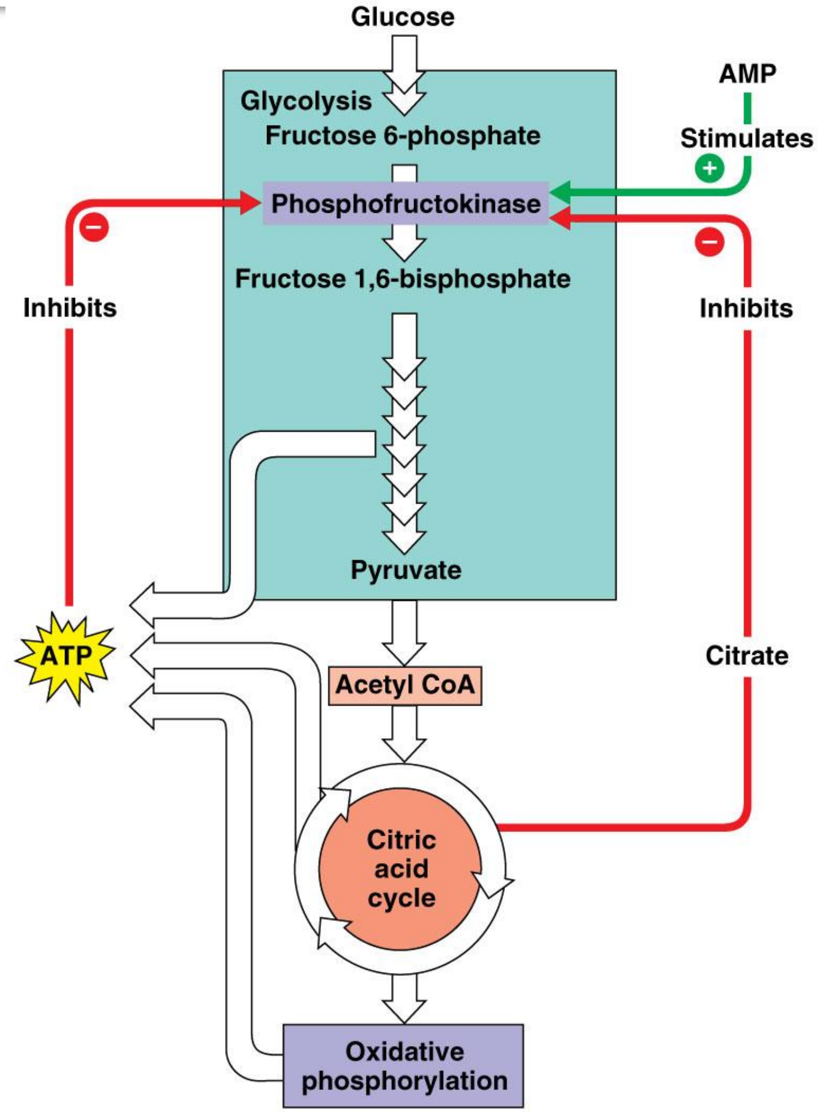


Why is this regulation important?

Balancing act:
availability of raw materials vs.
energy demands vs. synthesis

Phosphofructokinase:

- **Allosteric enzyme** that controls rate of glycolysis and citric acid cycle
- Inhibited by ATP, citrate
- Stimulated by AMP, ADP
  - AMP+ P + P →ATP



The Mystery of the Seven Deaths: A Case Study in Cellular Respiration

by

Michaela A. Gazdik
Biology Department
Ferrum College, Ferrum VA

Read Part 1 and STOP

DISCUSS!

1) Are there any similarities or connections between these 7 people?

2) What questions would you want to ask the families?

Read Part 2 and STOP

DISCUSS!

1) Recall the function of organelles. What function of the cells was interrupted in these patients?
2) Could this loss of function lead to the death of these individuals? Why or why not?
3) Given the autopsy data, were there any reports that seemed inconsistent with the immediate cause of death?

Read Part 3 and STOP

DISCUSS!

1) For each metabolite listed in the table:
   A. Describe its role in cellular respiration.
   B. Are they substrates or products?
   C. What is their main function?

2) Are there any abnormalities in the levels of these metabolites in the victims?

3) Develop a hypothesis about which pathway may be affected by these abnormalities. Explain.

Read Part 4

DISCUSS!

1) What affect would cyanide have on the electron transport chain and the production of ATP? Explain.

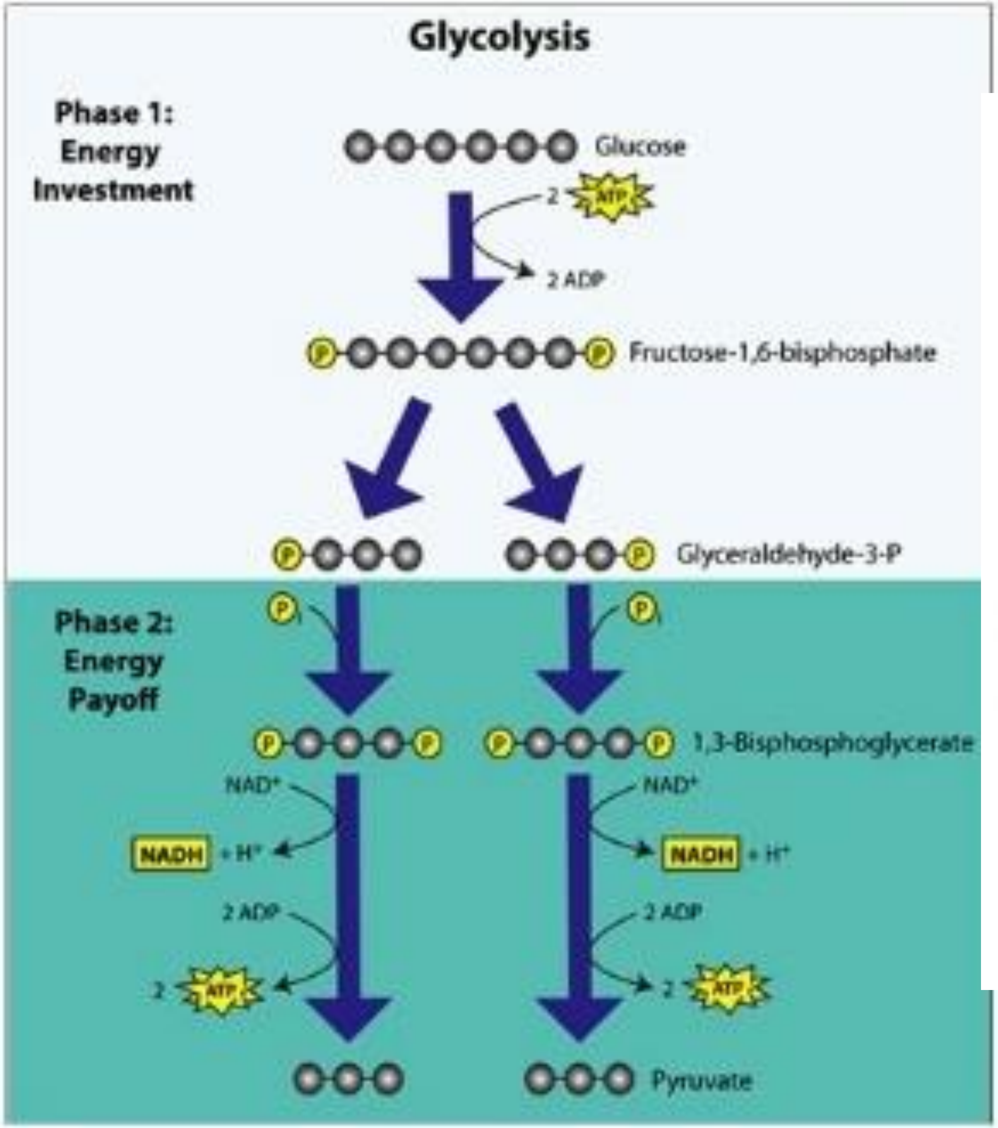
2) Given what you know about the action of cyanide on cellular respiration, explain why the patients died of lack of oxygen while their blood oxygen levels were normal.

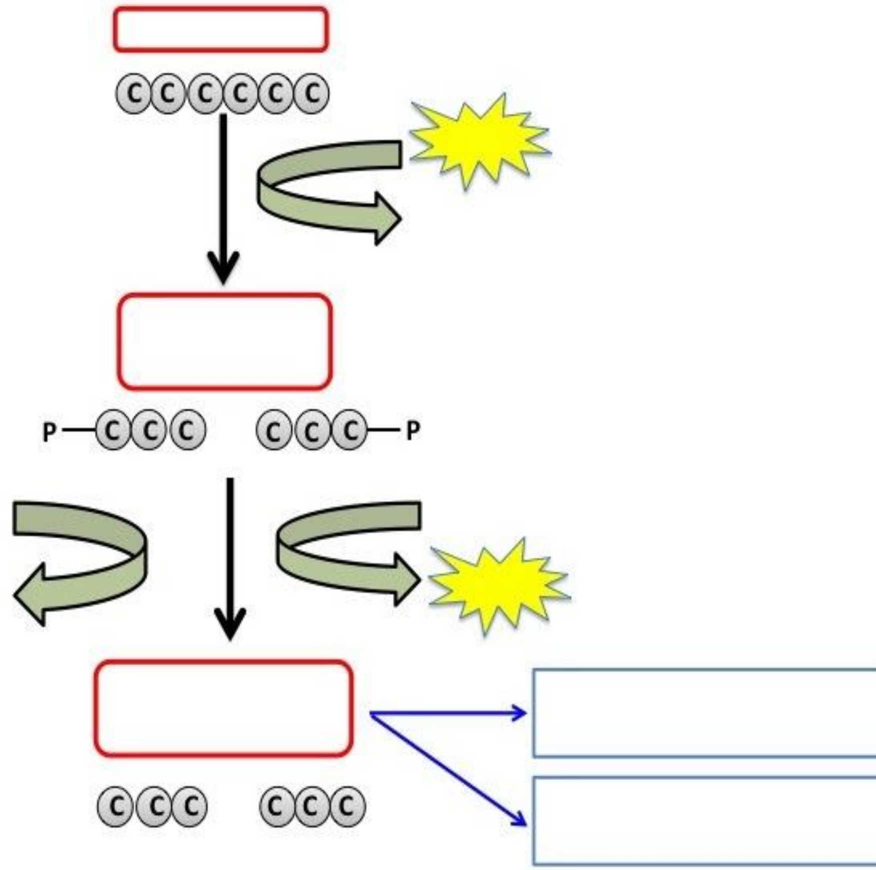
3) Would artificial respiration or oxygenation have saved these people? Why or why not?

4) Looking back at the information about the people before they got sick, suggest a possible source of the cyanide poisoning.

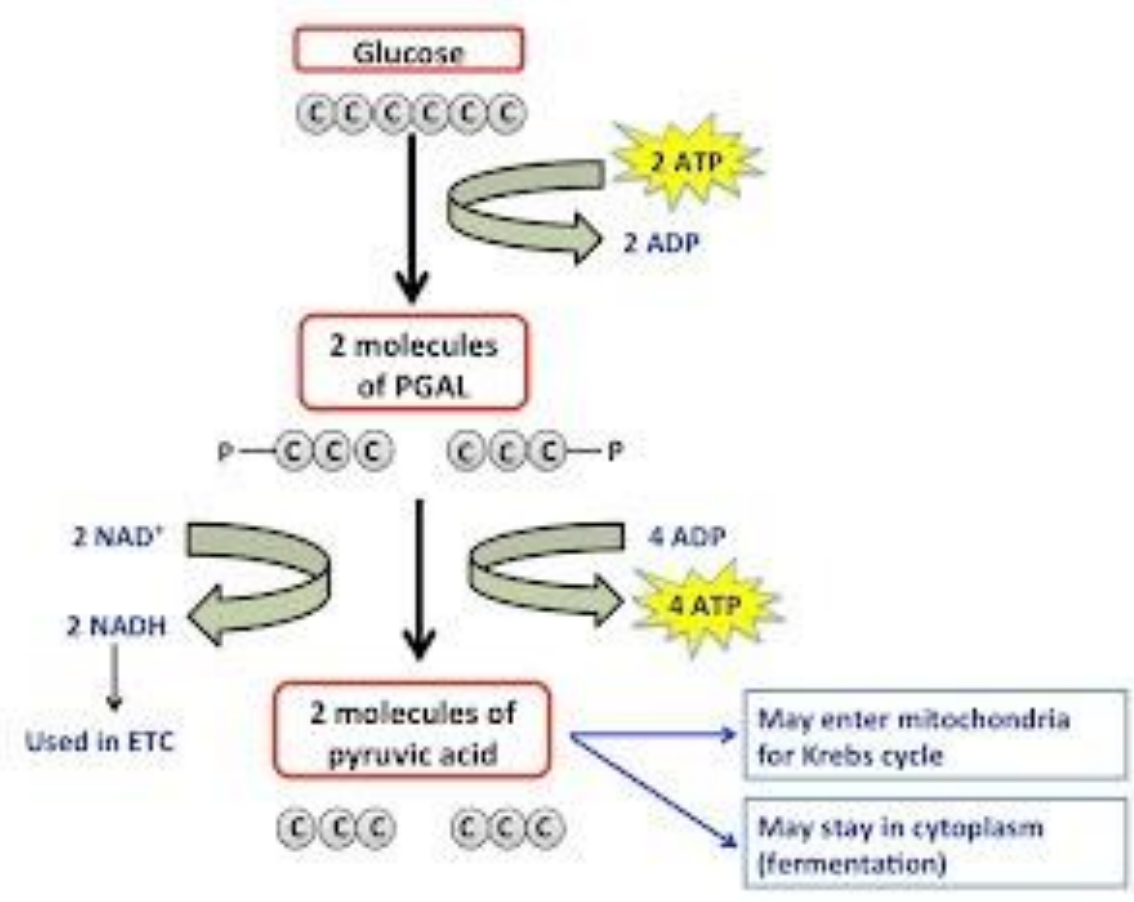
Cellular Respiration
2D Interactive Poster

- Work as a Group
- Each person must contribute to the poster (and be able to defend your work)
- Follow the rubric.
- Due by the end of class!


Glycolysis
Phase 1:
Energy
Investment
Glucose
2 ATP
2 ADP
Fructose-1,6-bisphosphate
Glyceraldehyde-3-P
Phase 2:
Energy
Payoff
1,3-Bisphosphoglycerate
NAD+
NADH + H+
2 ADP
2 ATP
Pyruvate



Worksheet Practice



Quizlet

- https://quizlet.com/_3whks7

- Play/Review with the flashcards first
- Then select 1 game to play either alone or with a partner
  - Record your time: _______

Bean Brew…an Investigative Case

- **Close Read**
  - ? And !
  - Highlight key vocab terms
- Work to complete the questions throughout the investigation (Parts I-II)in your lab groups.
- Answer in complete sentences in the packets.
- Use the textbook to refer to the indicated diagrams in ch. 7, 8, and 9.
- Choose ***either*** Part IV or V to complete **at home**. Due date = Monday Nov. 6

“The Mystery of the Seven Deaths”

- Read the Case Study and answer the questions.
- Discuss with someone near you if you aren’t sure!
- Write your answers in the white space but be sure to use COMPLETE sentences that clearly address the question.