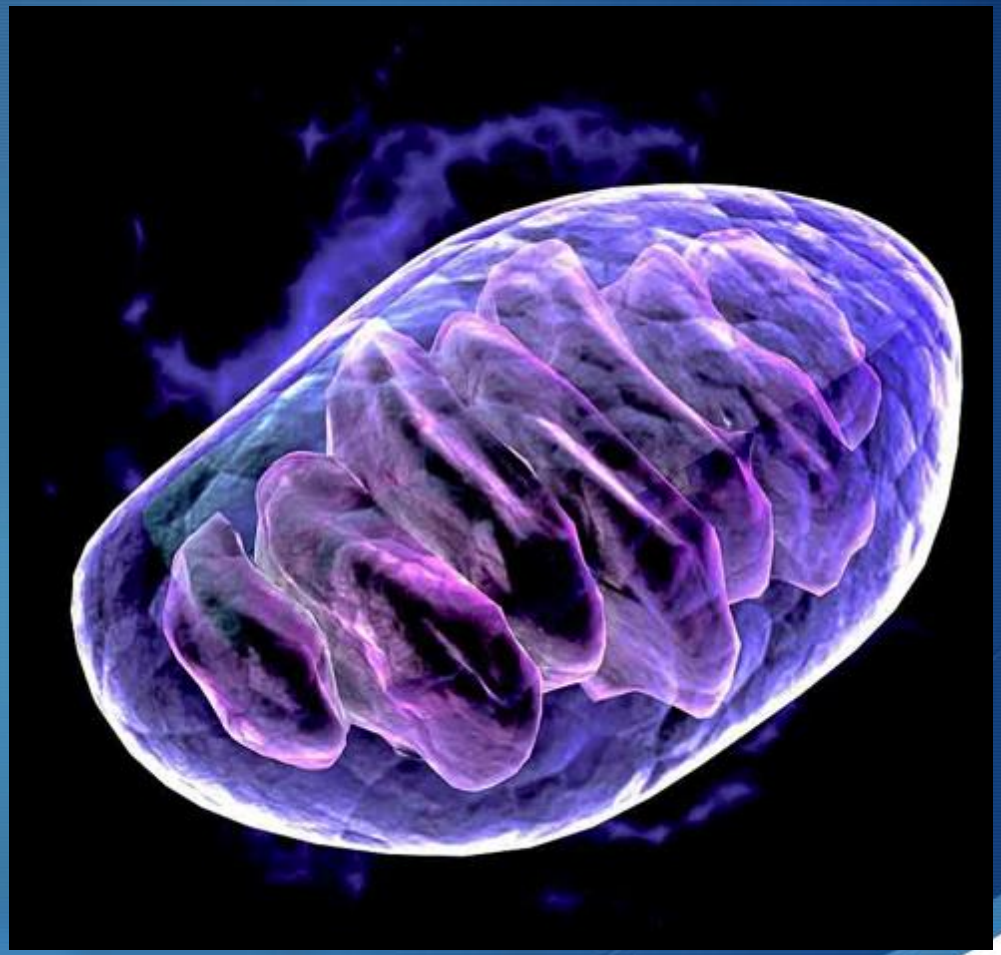
Go to the "Slide Show" shade above

Click on "Play from Beginning"

Chapter 8B: Cellular Respiration

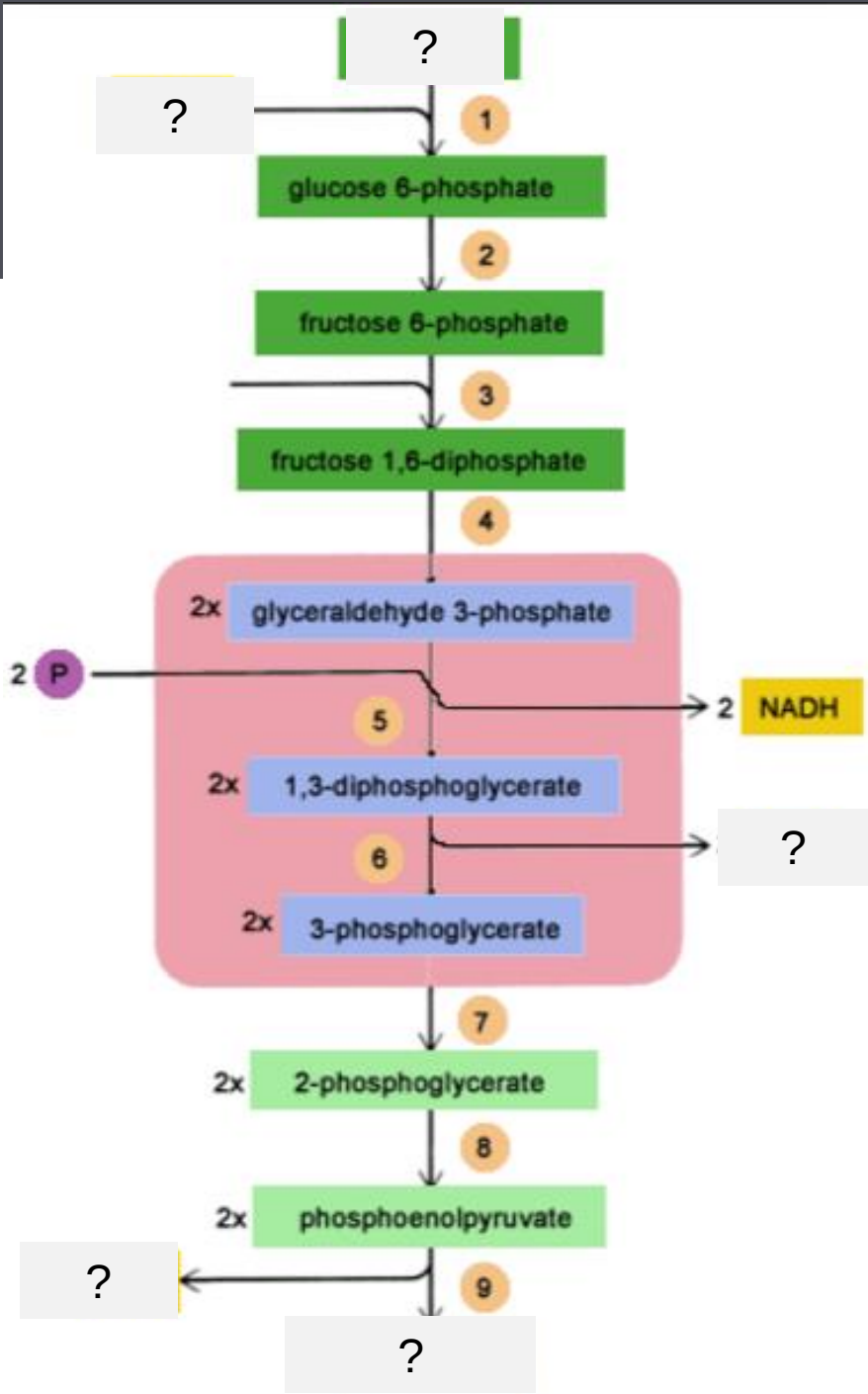
Krebs Cycle



WARM-UP

Review

- What process is shown in the image?
- Define the term (above).
- Label the diagram to the right.
- How is NADH formed (what chemical process)?
- How many carbons are in glucose and pyruvate?
- What is the net energy production?

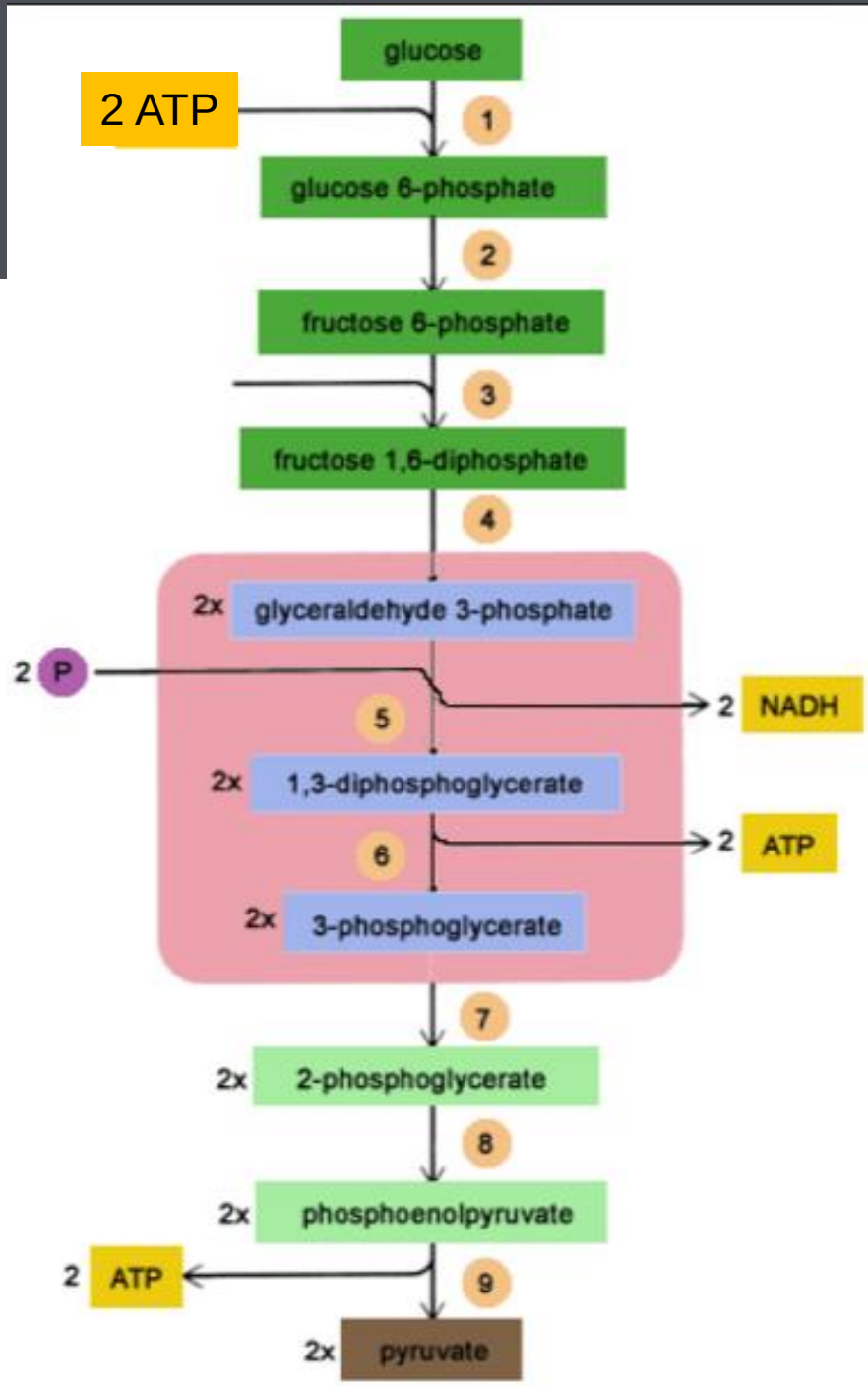


WARM-UP

Review

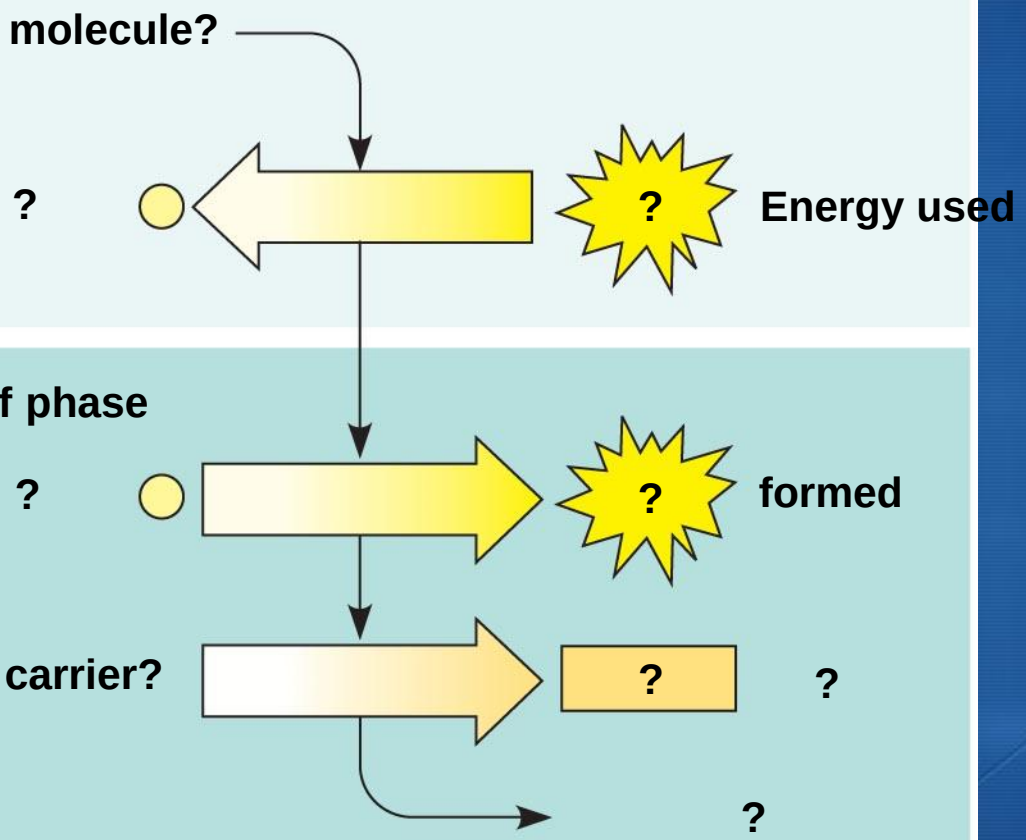
- What process is shown in the image?
  glycolysis
- Define the term (above).
  "Sugar Splitting"
- Label the diagram to the right.
- How is NADPH formed (what chemical process)? NAD+ is **reduced** (gains e- and H+ ion)
- How many carbons are in glucose (6) and pyruvate (3)?
- What is the net energy production?

2 ATP added → 4 ATP produced
= 2 ATP (net)



WARM-UP

Process? - Energy investment phase



Net

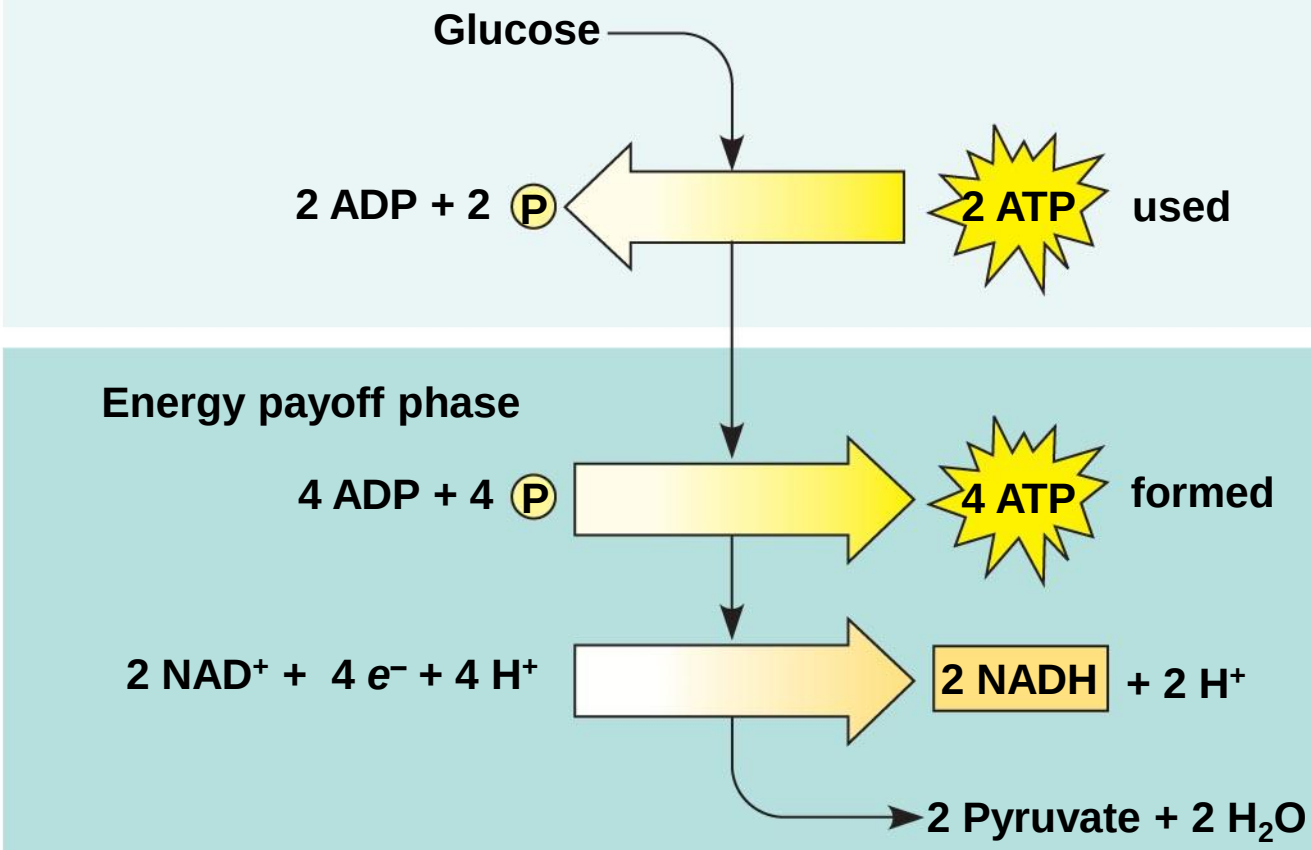
? organic molecule → ?

energy formed – ? used → ?

Electron carrier? → ?

WARM-UP

Glycolysis - Energy investment phase



Net

Glucose → **2 Pyruvate** + 2 H_2O

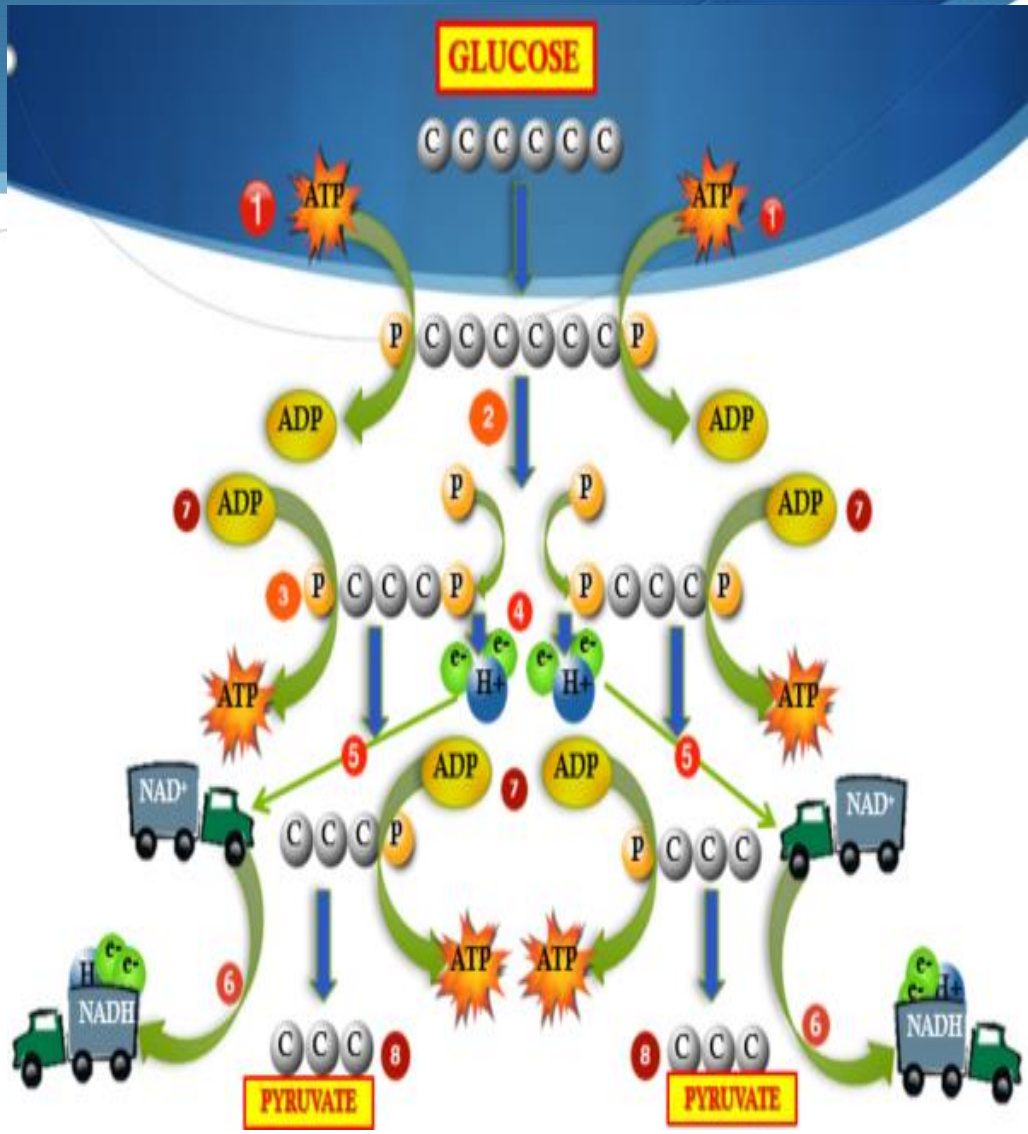
4 ATP formed – 2 ATP used → 2 ATP

2 NAD^+ + 4 e^- + 4 H^+ → 2 NADH + 2 H^+

WARM-UP

1. Glycolysis Summary

- ✓ Takes place in the _____.
- ✓ _____ (no oxygen).
- ✓ Glucose "splits" into two 3-carbon molecules of _____.
- ✓ NAD+ is _____ by gaining electrons & produces _____.
- ✓ "_____" of 4 ATP.
- ✓ Requires an _____ of 2 ATP.
- ✓ **Net ATP production = _____.**

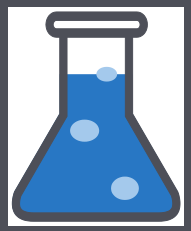


WARM-UP

1. Glycolysis Summary

- ✓ Takes place in the **Cytoplasm.**
- ✓ **Anaerobic** (no oxygen).
- ✓ Glucose "splits" into two 3-carbon molecules of **Pyruvate.**
- ✓ NAD+ is **reduced** by gaining electrons & produces **2 NADH.**
- ✓ **Phosphorylation** to make 4 ATP.
- ✓ Requires an **input** of 2 ATP.
- ✓ **Net ATP production = 2 ATP.**

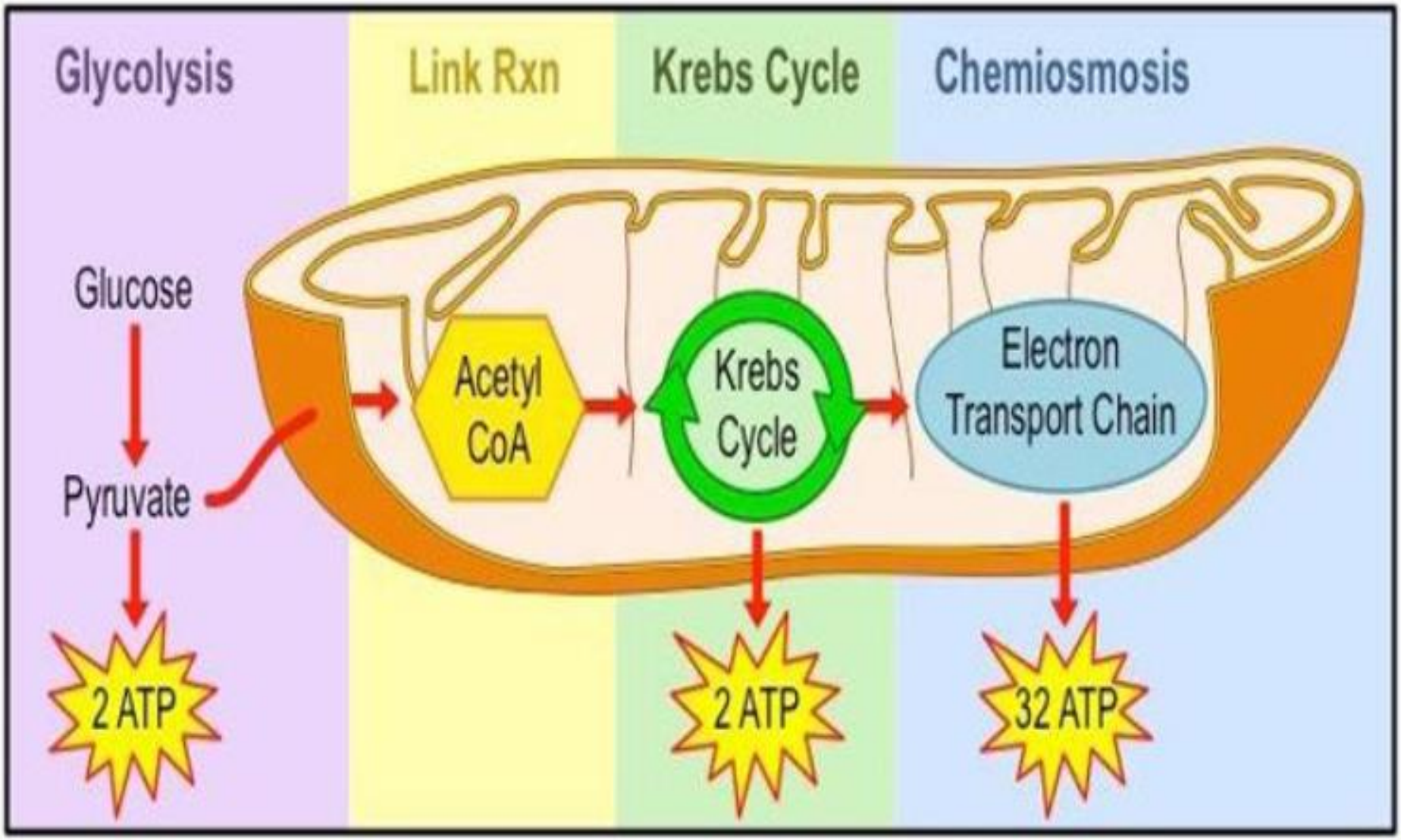
Lesson Objectives



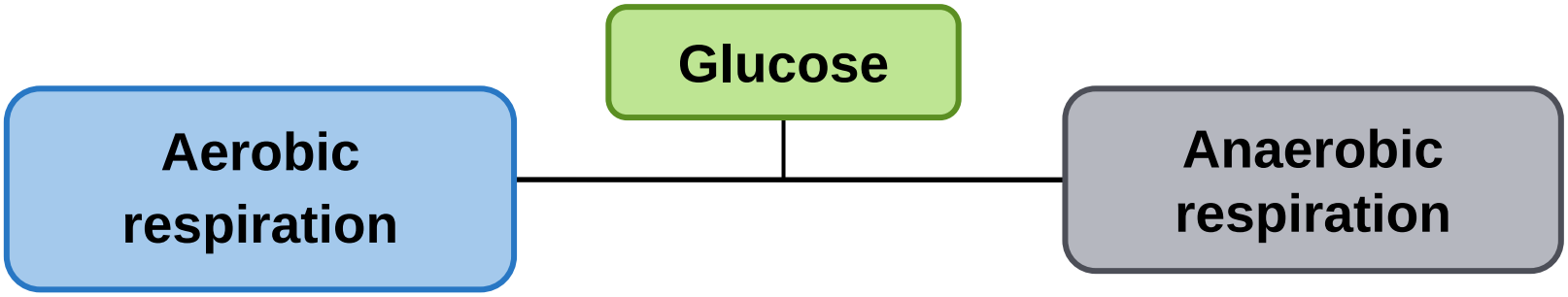
By the end of this lesson, you should be able to:

- Understand how energy is acquired by organisms.
- Investigate the biological processes of Cell Respiration
- Analyze the steps of Cellular Respiration: Glycolysis, Transition Reaction, the Krebs Cycle, and the Electron Transport Chain.
- Distinguish aerobic from anaerobic respiration.
- **Science Practice: Simulation Cell Respiration**

Cellular Respiration Overview (4 Stages)



Cellular Respiration Overview (3 Major Stages)



(**Oxygen present**)

Glycolysis: **2 ATP**

Citric acid cycle: **2 ATP**

Electron transport chain **ETC**

(up to 32 ATP)

Total = 36 ATP

(**No oxygen present**)

Glycolysis: 2 ATP

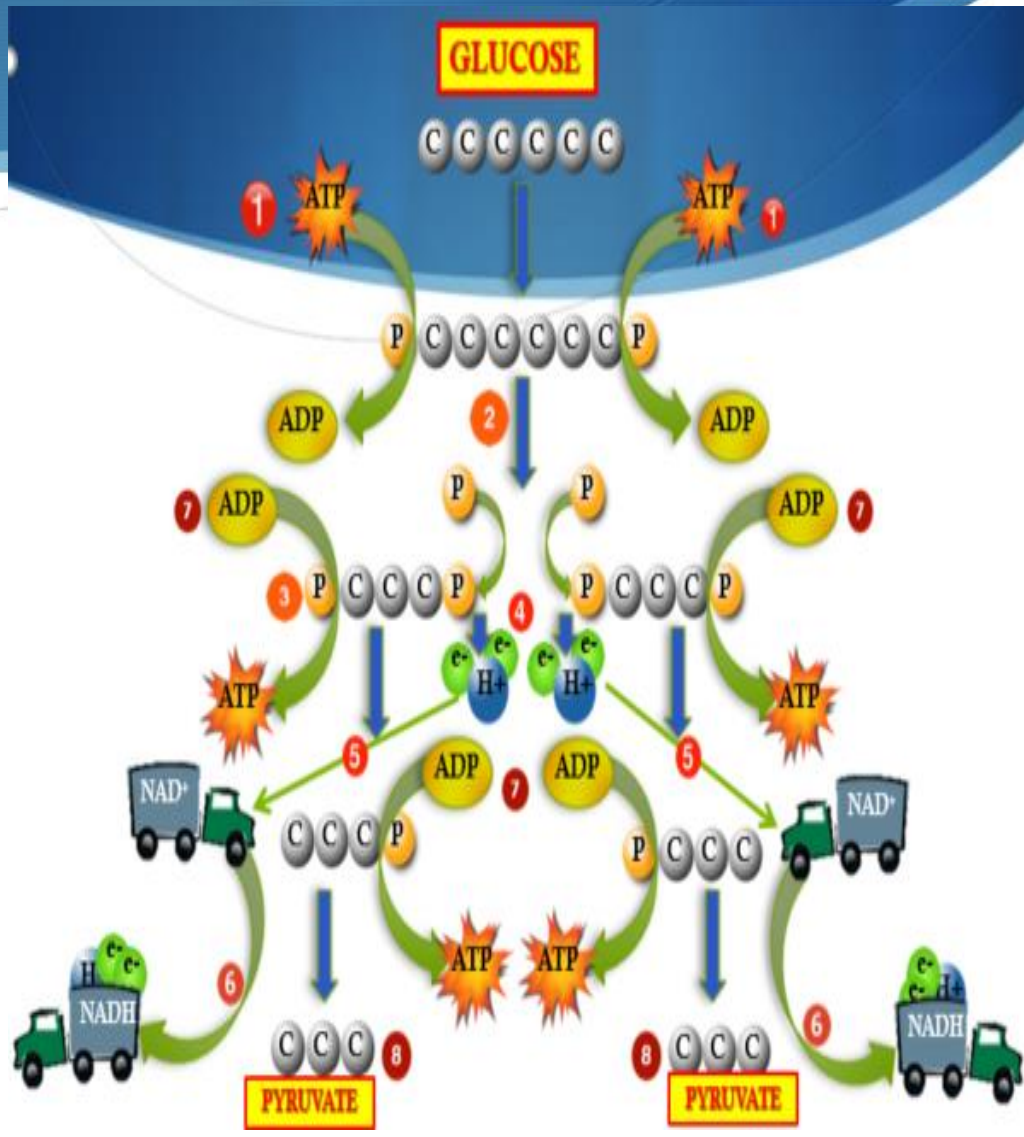
Fermentation: 0 ATP

Total = 2 ATP

Molecular Accounting of Glycolysis

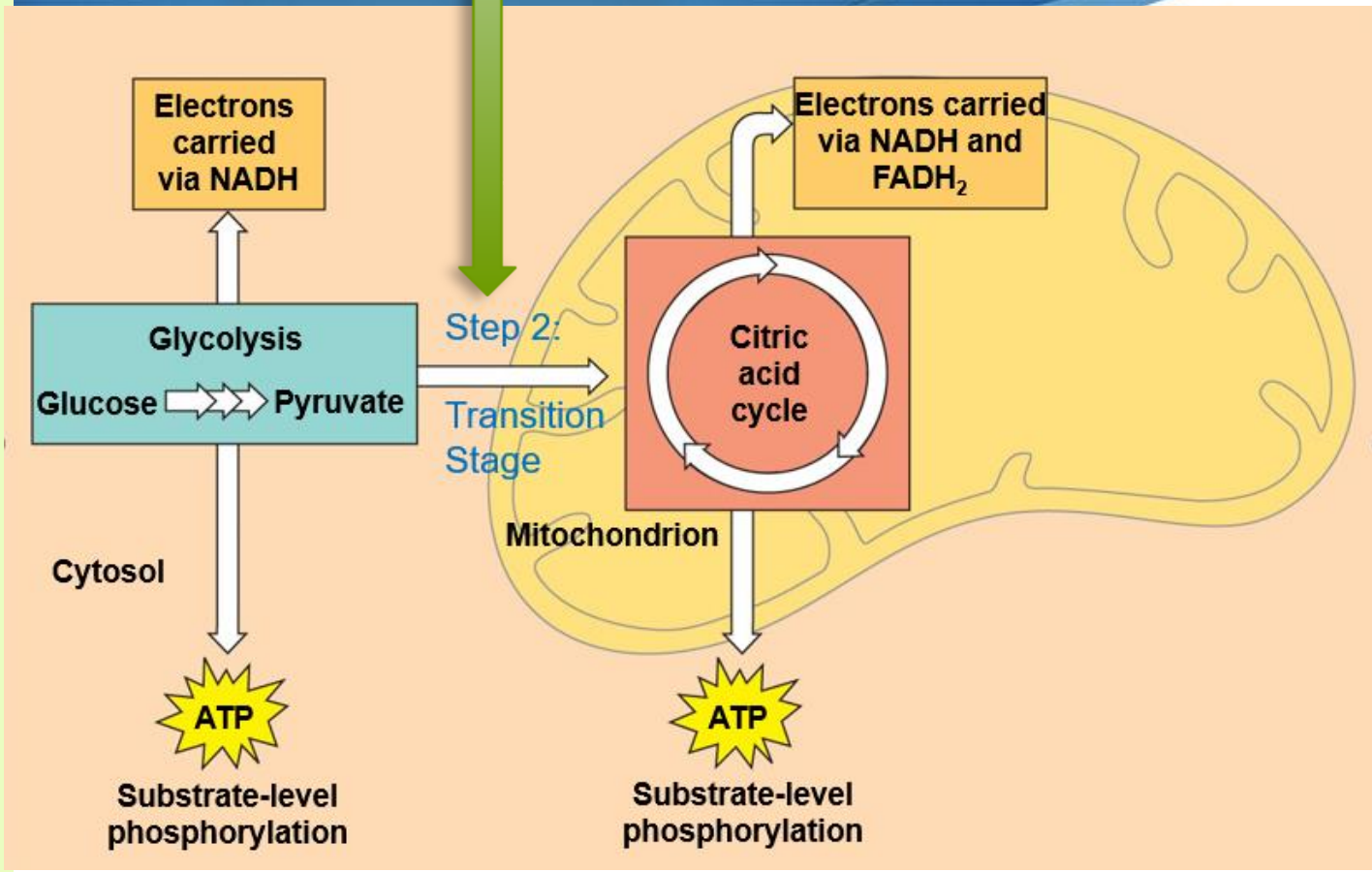
Glycolysis:

- One 6-carbon glucose molecule
- Two **3-Carbon Pyruvate** molecules
- **2 ATP** (4 are produced but 2 are used)
- **2 NADH**

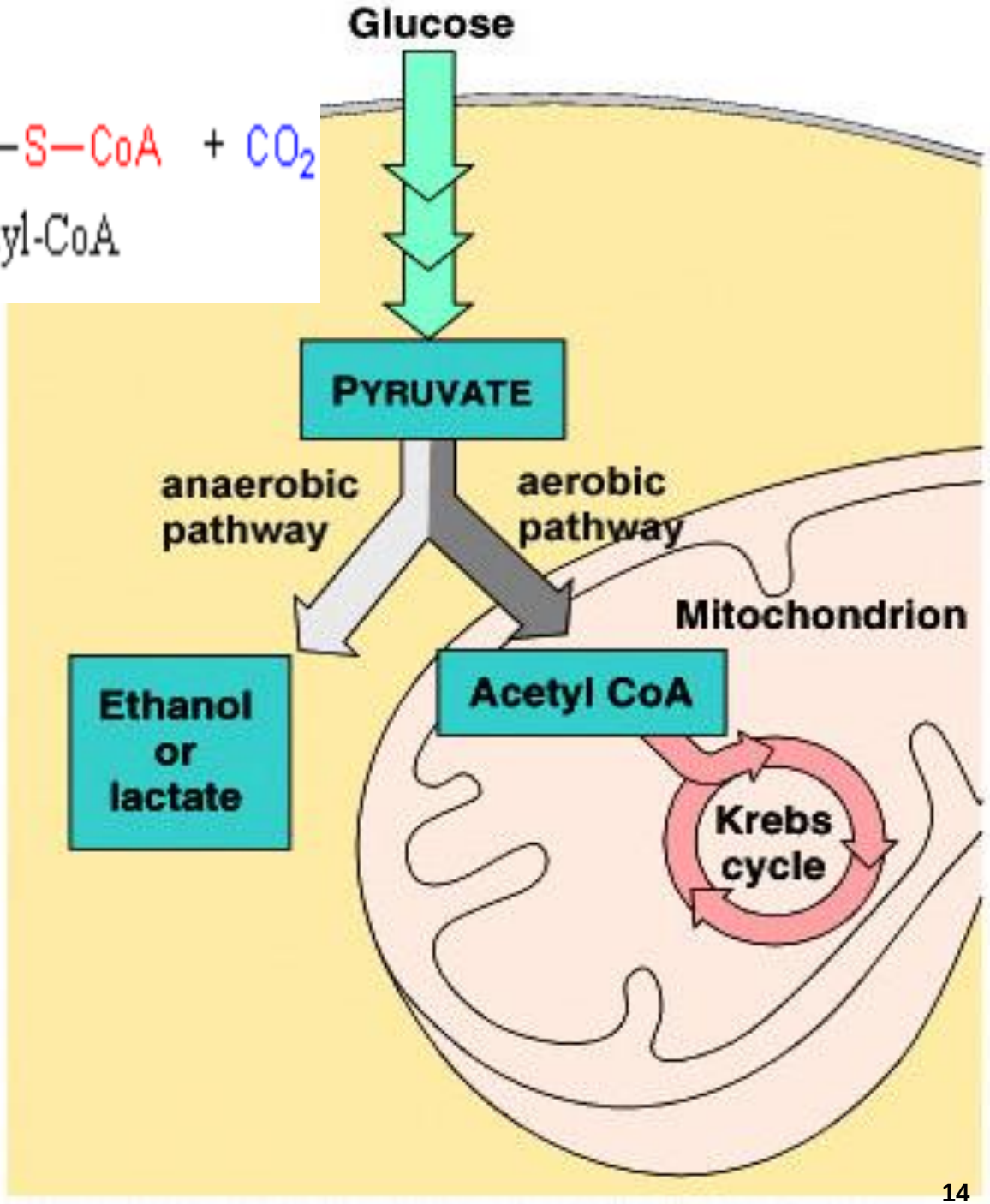


Transition (link) Reaction

- 2 Pyruvates enter the **Mitochondria** per glucose molecule
- It occurs in the **Matrix** of the mitochondria
- When pyruvate enters the mitochondria, it undergoes a **Transition Reaction**.

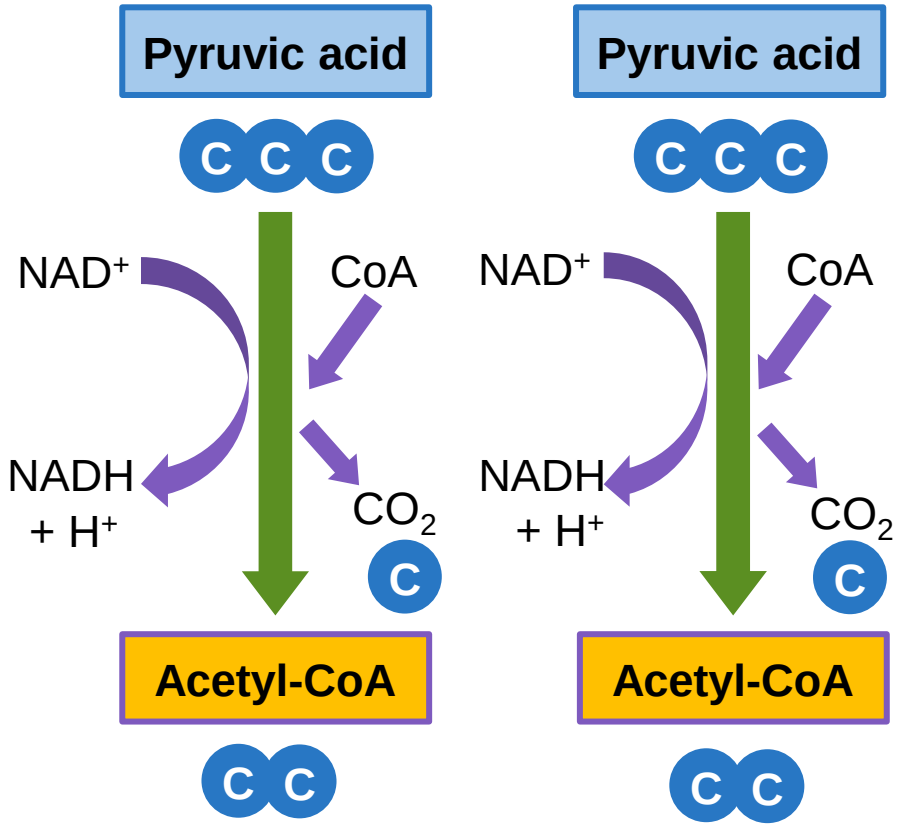


Transition Reaction



Transition (Link) Reaction

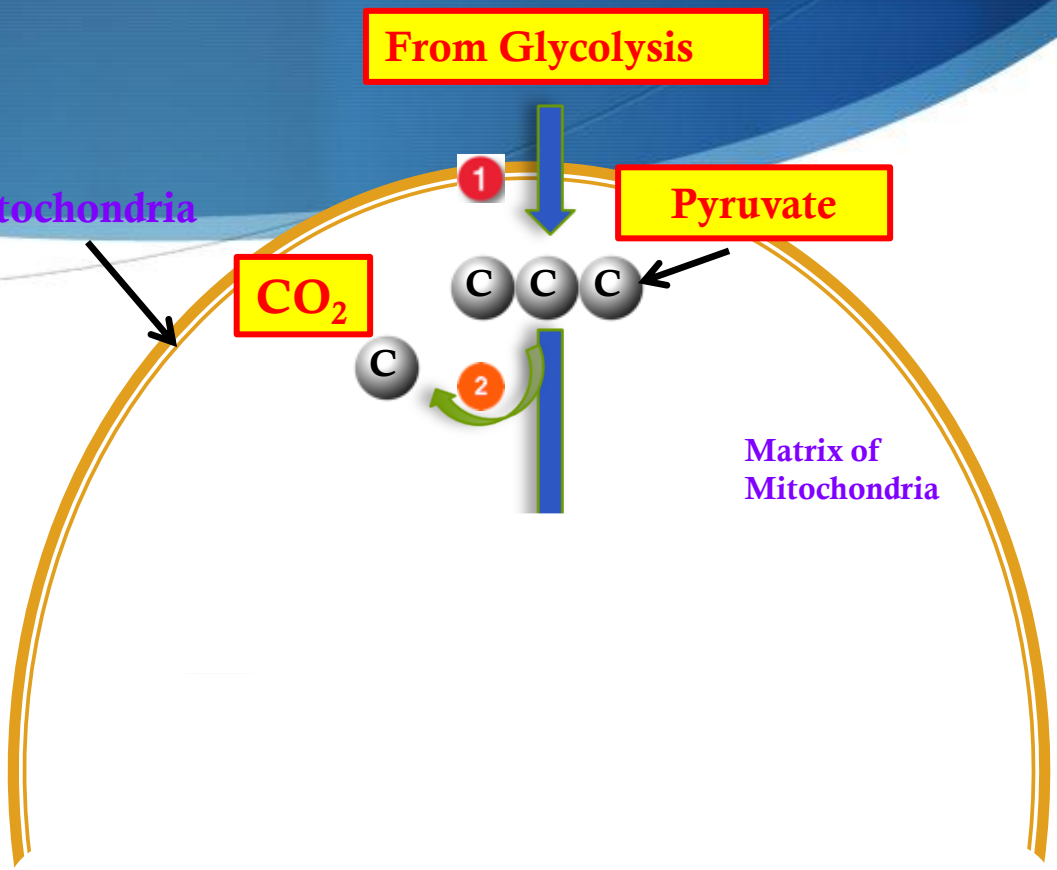
- 2 **Pyruvic Acid** molecules (pyruvate) are converted into 2 acetyl-CoA (from glycolysis).
- **Acetyl Co-A** (2 carbon molecule) connects glycolysis to the **Citric Acid cycle** (*Stage 2 of cellular respiration*).
- **NAD+** is **REDUCED** to **NADH** by gaining H+ and electrons, entering the **Electron Transport Chain** (ETC). (*Stage 3 of cellular respiration*).



Transition Reaction Summary

1. Each pyruvate enters **Matrix** of the mitochondria from glycolysis.
2. Pyruvate releases one CO_2 molecule.

Transition Reaction Summary



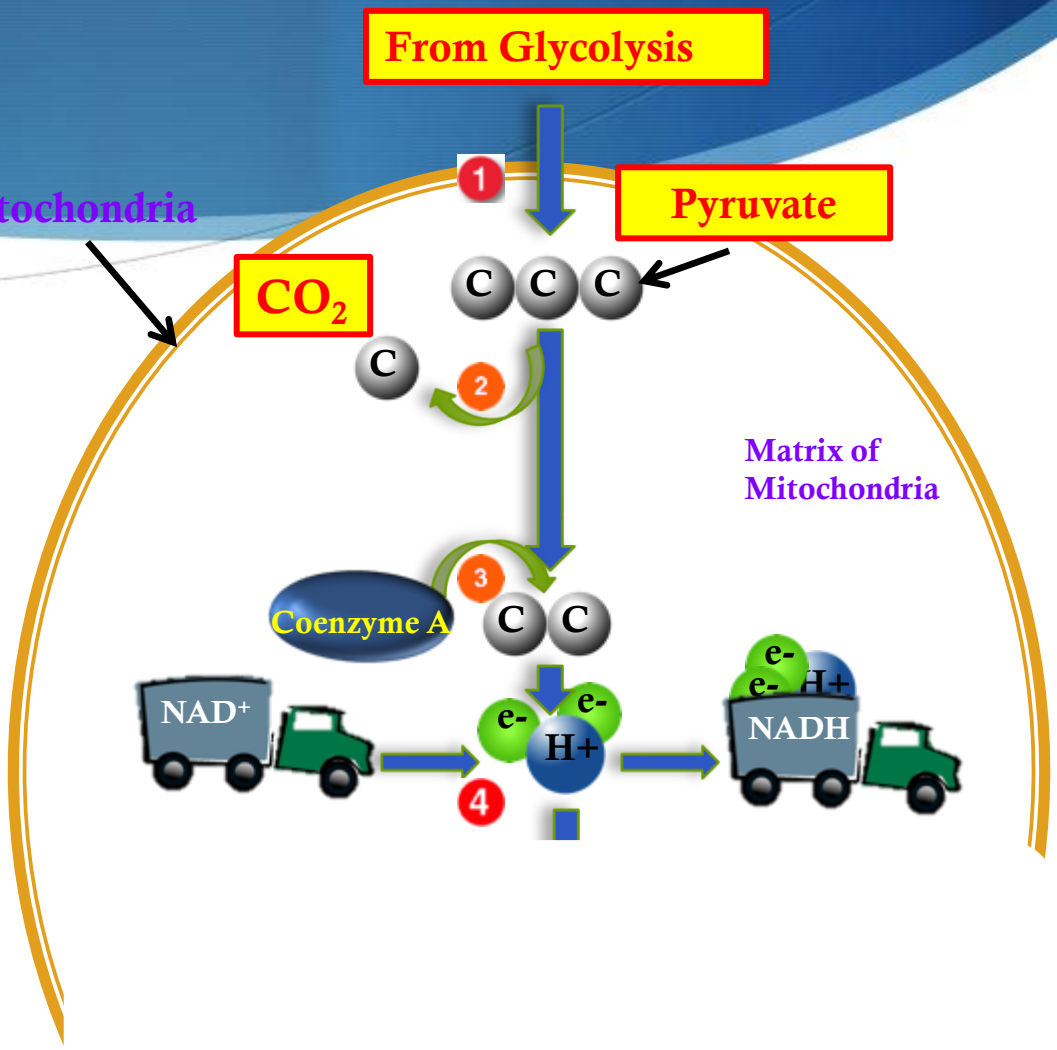
3. The remaining portion of the molecule is attached to **Coenzyme-A** (2 carbon molecule).

   This releases H+ & two electrons.

4. NAD+ is reduced by gaining H+ and electrons which creates **NADH.**

Transition Reaction Summary

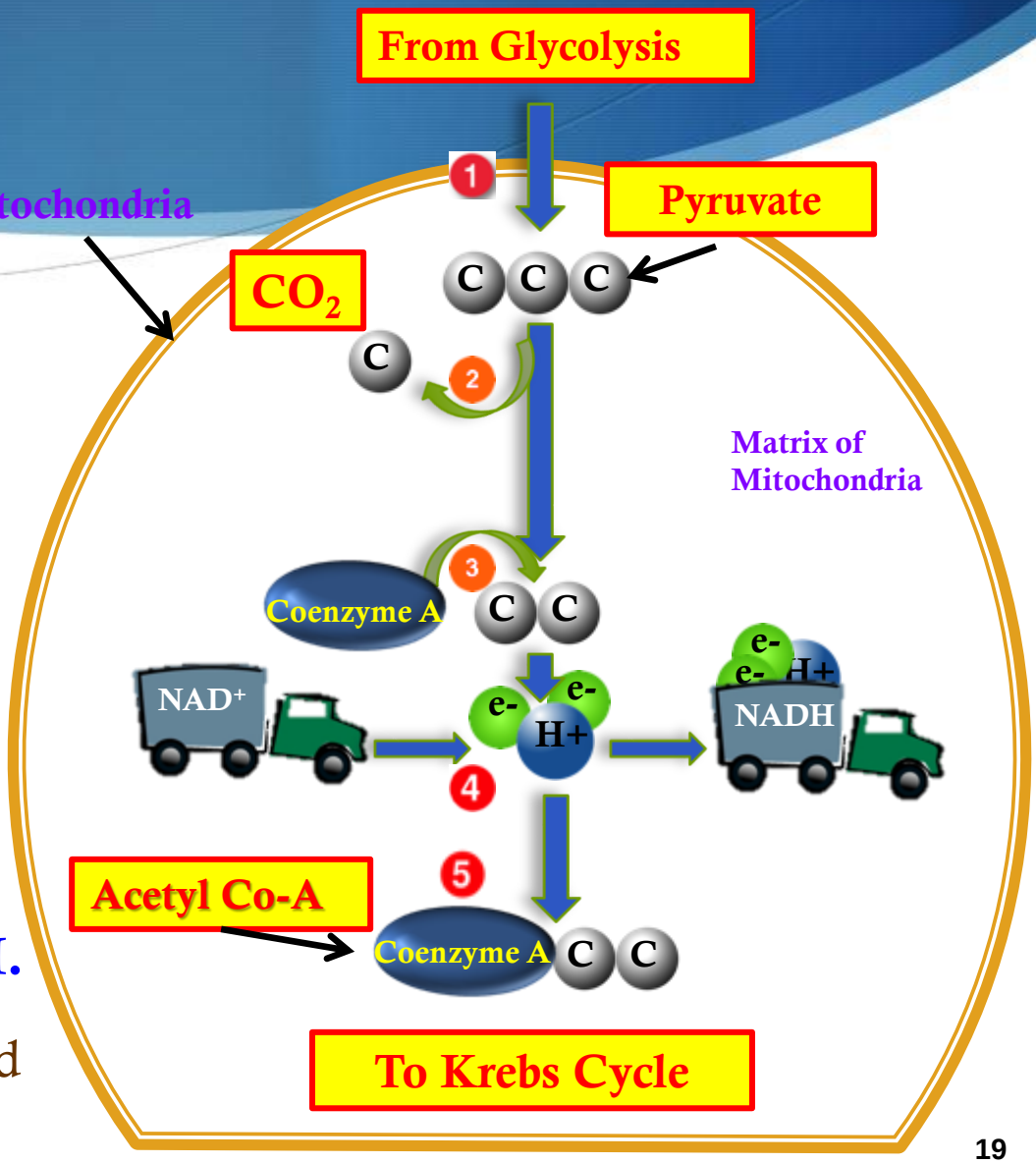
5. Coenzyme-A joins with Acetic Acid to form **Acetyl Co-A**.



Transition Reaction Summary

1. Each pyruvate enters **Matrix** of the mitochondria from glycolysis.
2. Pyruvate releases one CO_2 molecule.
3. The remaining portion of the molecule is attached to **Coenzyme-A** (2 carbon molecule).

   This releases H+ & two electrons
4. NAD+ is **reduced** by gaining H+ and electrons which creates **NADH.**
5. Coenzyme-A joins with Acetic Acid to form **Acetyl Co-A.**

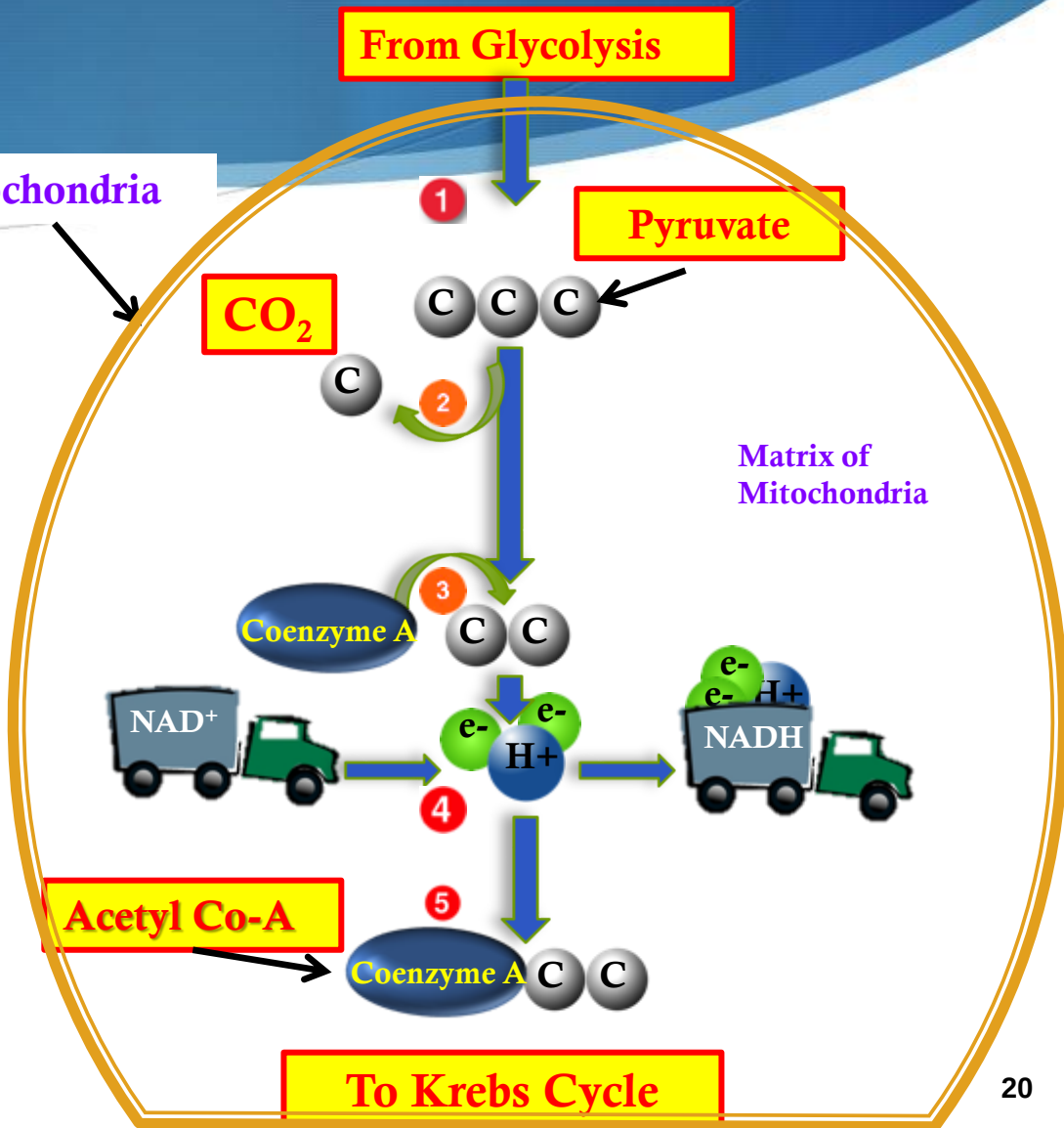


Molecular Accounting in Transition Reaction

Transition Reaction:

- 2 **Acetyl Co-A** molecules
- 2 **Carbon Dioxide** molecules
- 2 **NADH**

[one of each per Pyruvate molecule]



Transition Stage

Where does it occur?

What is used?

What molecule is produced?

What are the electron carriers produced? Process?

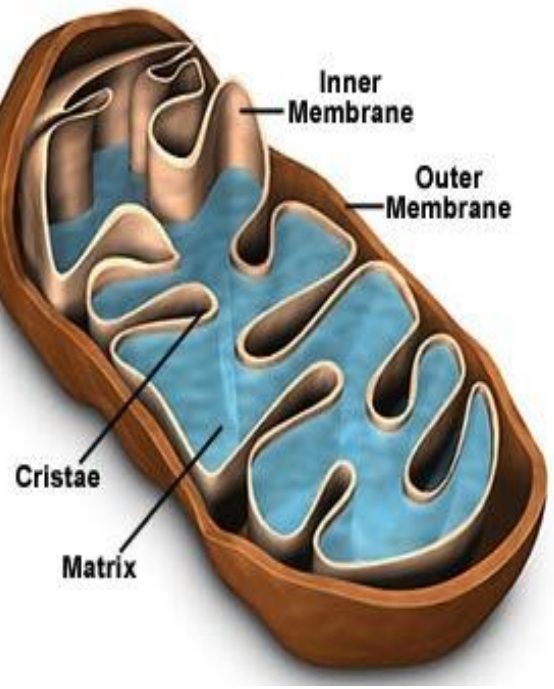
Transition Stage

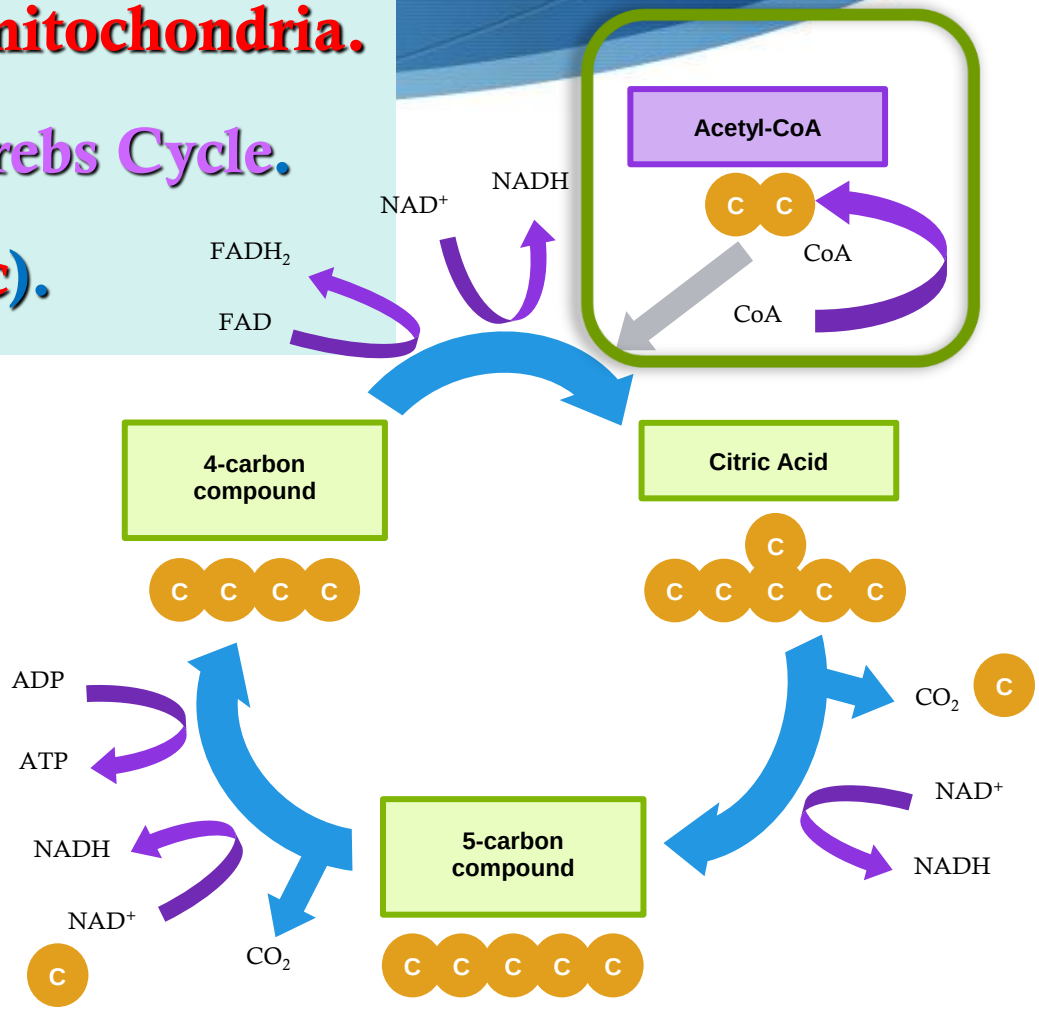
1. Where does it occur?
   - **Starts in cytoplasm**
   - **Ends in mitochondria**
2. What is used?
   - **Pyruvate**
3. What molecule is produced?
   - **2 CO_2**
4. What are the electron carriers produced? Process?
   - **2 NADH, 2 Acetyl CoA … reduction**

Stage 2: Krebs Cycle

Citric Acid Cycle

- Takes place in matrix of mitochondria.
- Acetyl Co-A enters the Krebs Cycle.
- Requires Oxygen (Aerobic).





2. Krebs Cycle

1. **Acetyl CoA** enters the mitochondria from the **Transition Reaction**.

1. **From Transition Reaction**

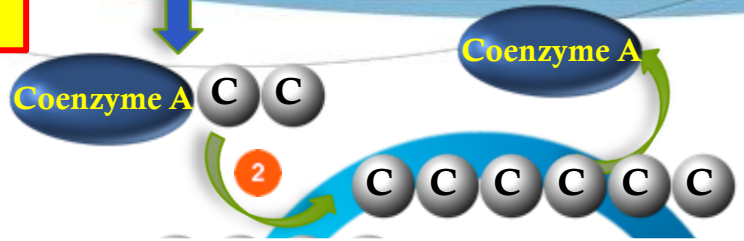
Acetyl Co-A

2. Krebs Cycle

2 **Acetyl Co-A** (a two carbon molecule) joins with a **4 Carbon molecule** forming a 6 Carbon molecule.

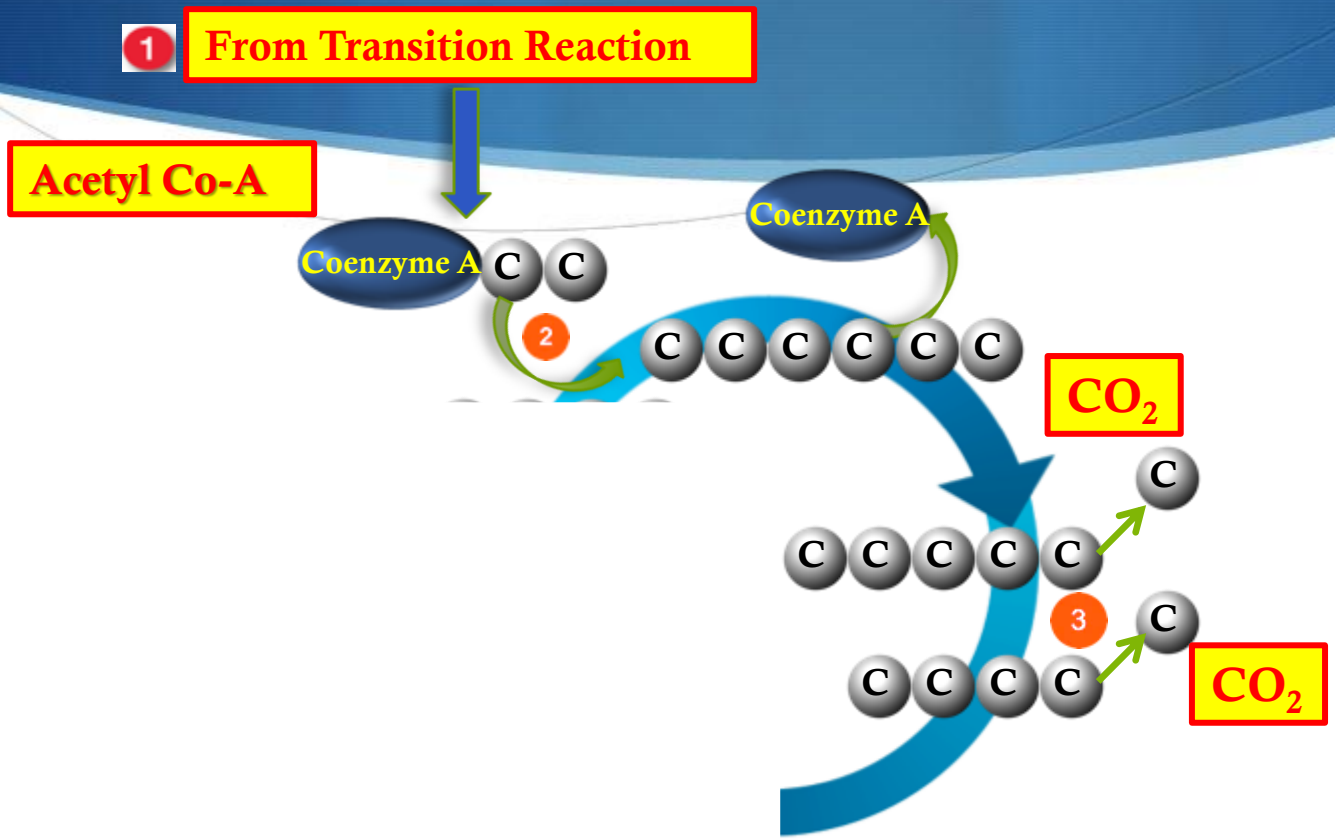
1 **From Transition Reaction**

Acetyl Co-A



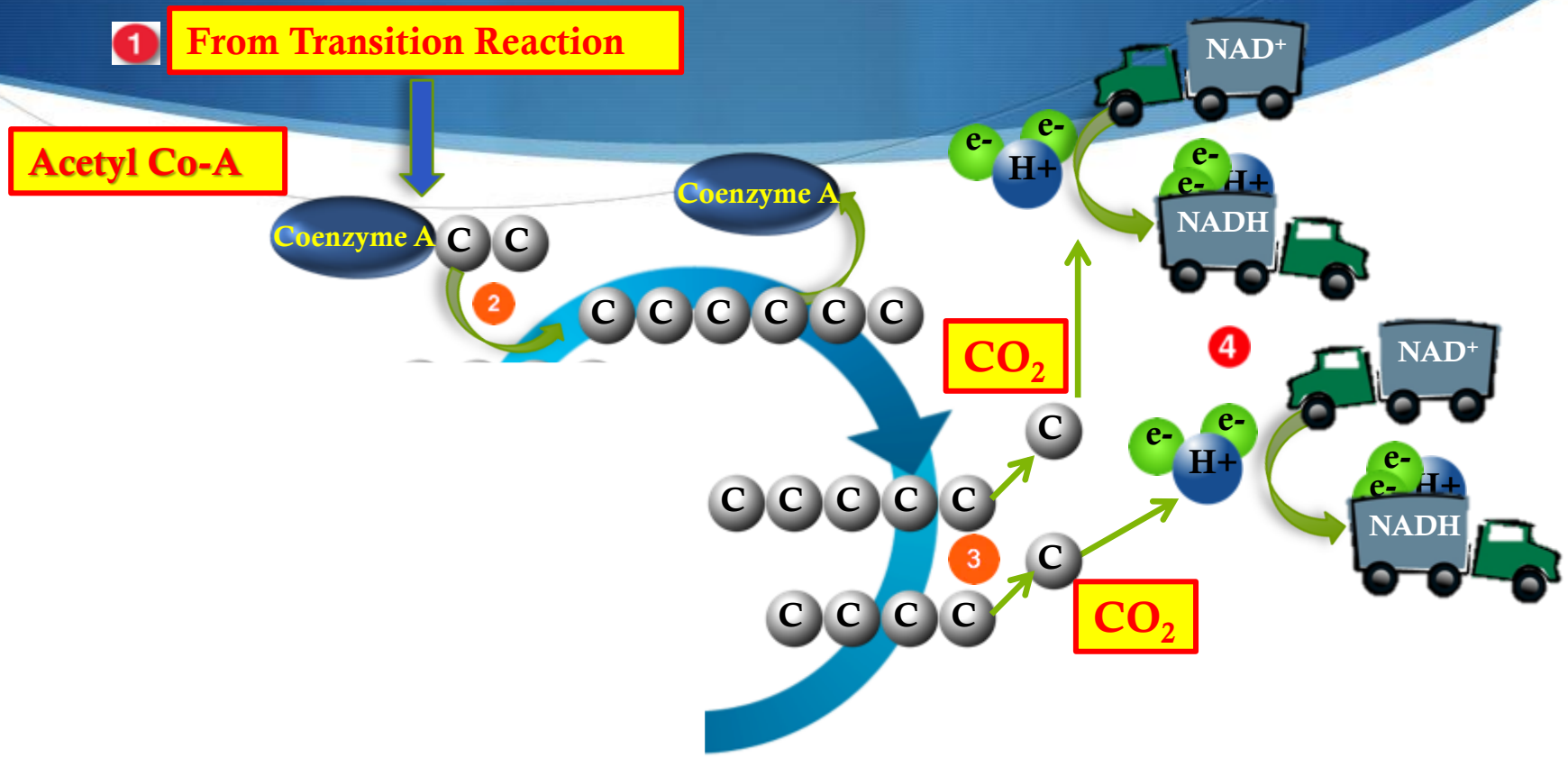
2. Krebs Cycle

3 Two carbons break off this molecule releasing **2 Carbon Dioxide** molecules.



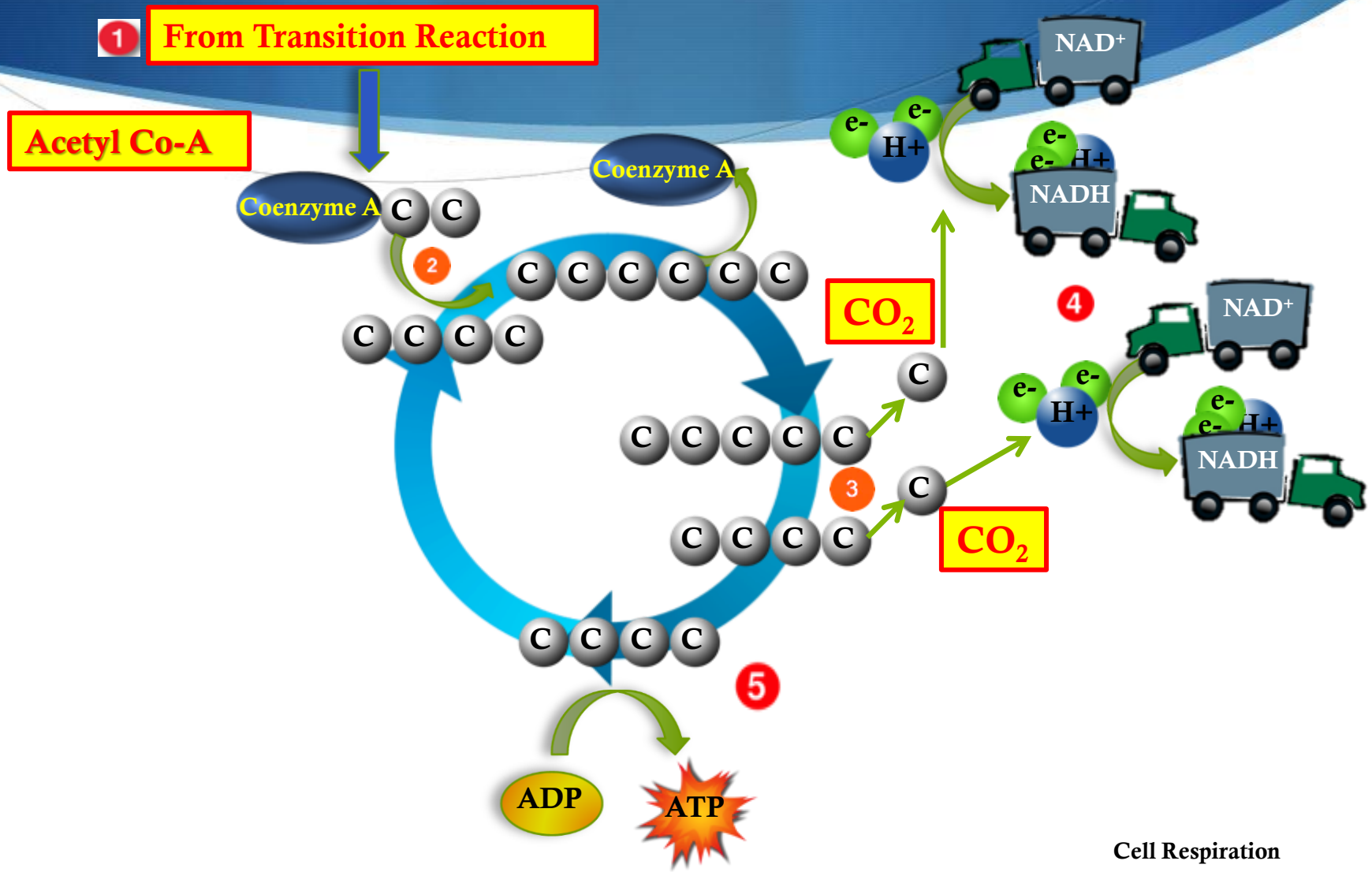
2. Krebs Cycle

4 The Hydrogen and Electrons released by each reaction form **2 NADH** (reduction).



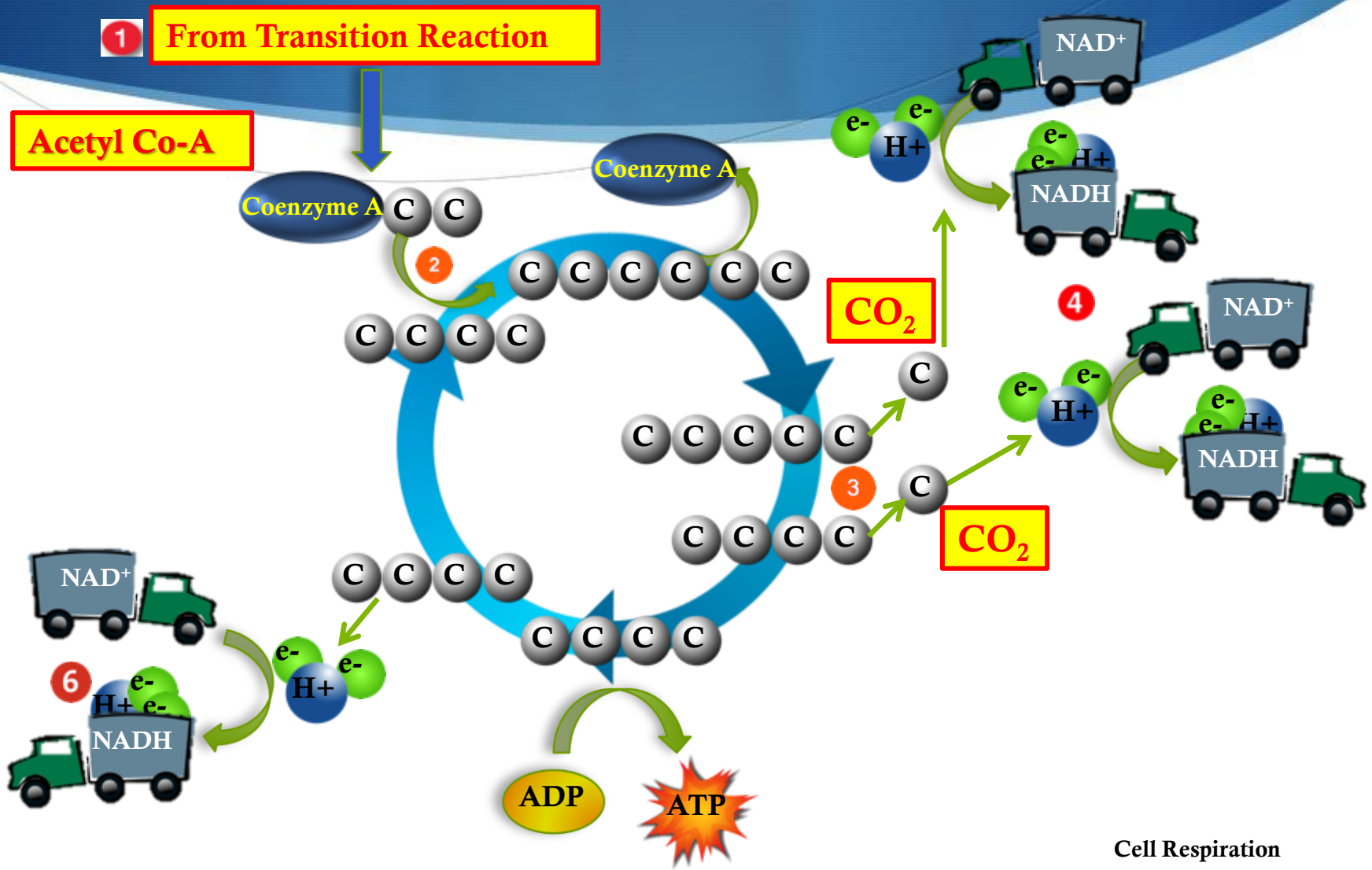
2. Krebs Cycle

5 This 4 carbon molecule reacts with ADP forming **ATP.**



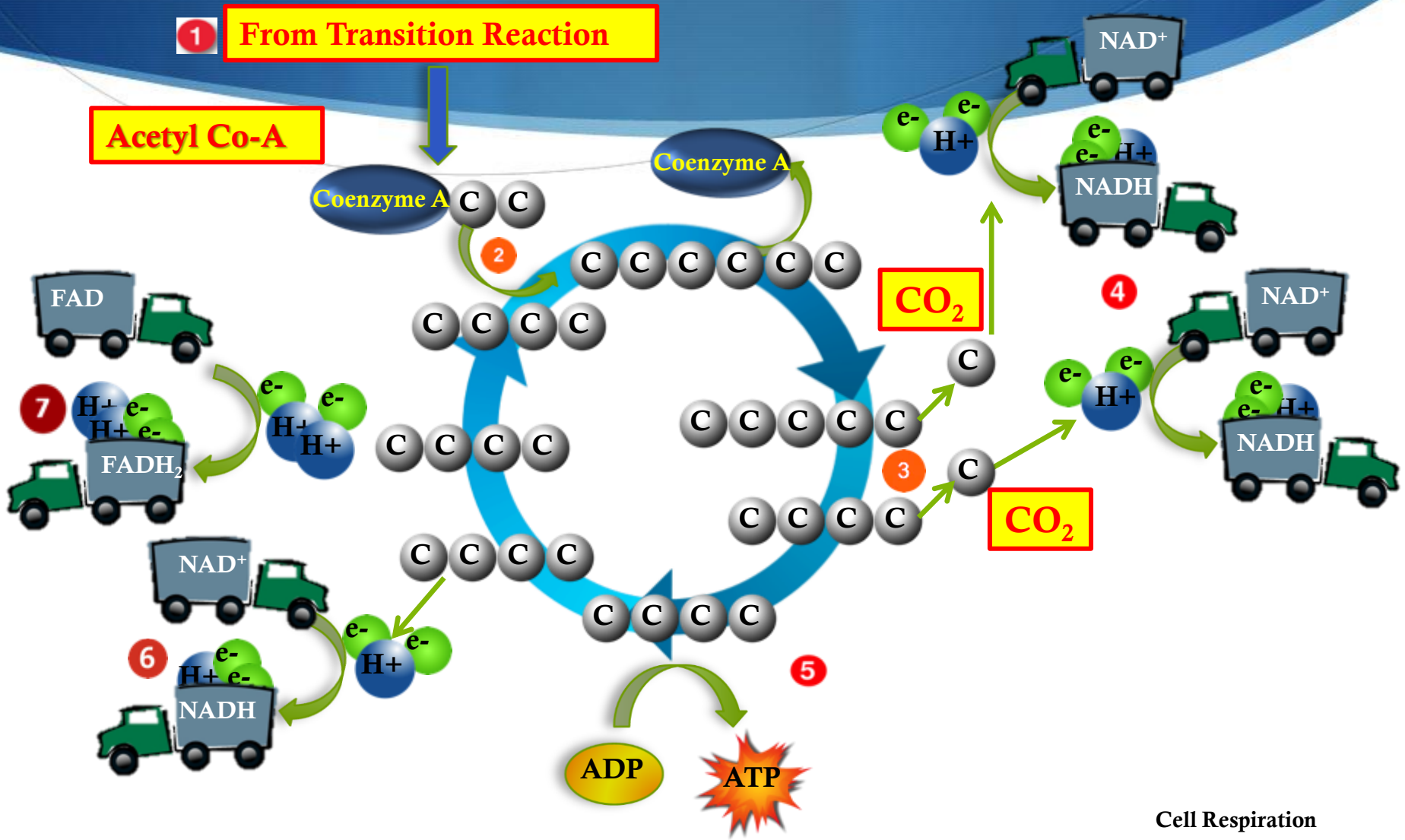
2. Krebs Cycle

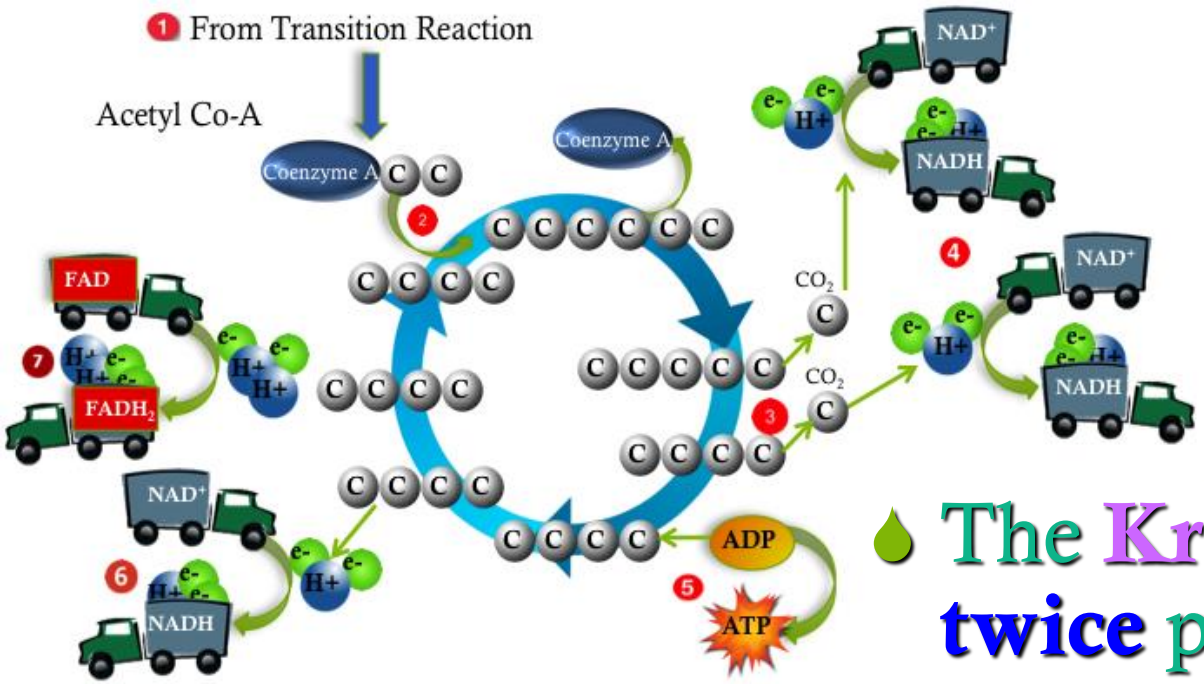
6 Then the 4 carbon molecule releases H+ and 2 Electrons to form another NADH.



2. Krebs Cycle

7 Then it releases 2 H+ and 2 electrons to form $FADH_2$



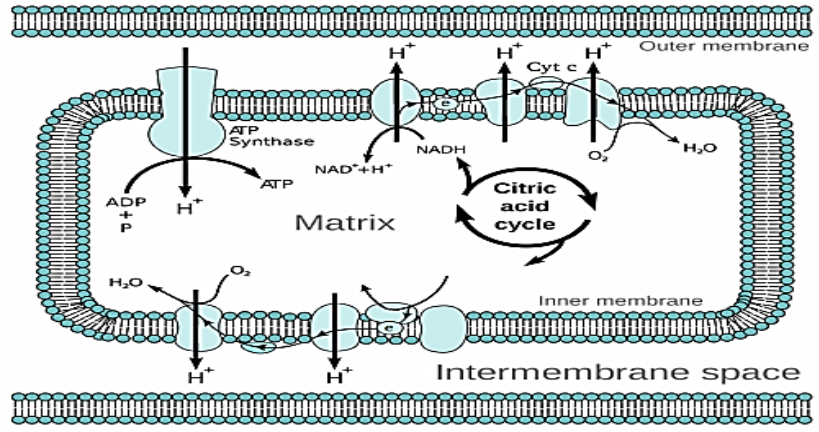


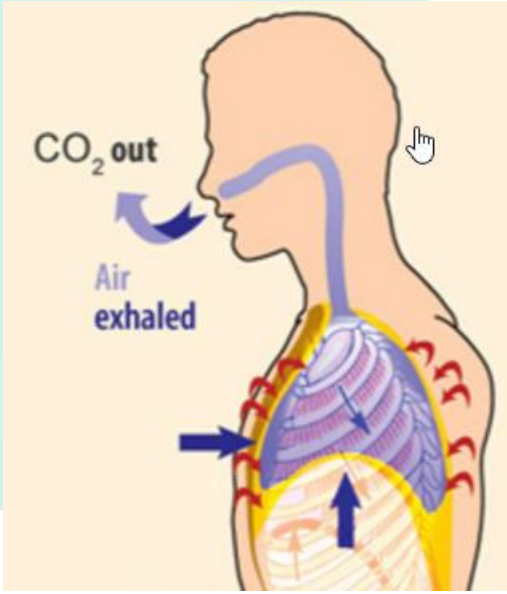
Molecular Accounting in the Krebs Cycle

- The Krebs Cycle turns **twice** per **glucose** molecule.
- **Per Glucose** molecule it produces:
  - **4 CO_2** (2 per turn)
  - **2 ATP** (1 per turn)
  - **6 NADH** (3 per turn)
  - **2 $FADH_2$** (1 per turn)

Krebs Cycle Follow Up

- **ATP** is used directly by the cell for **ENERGY.**
- **NADH** and **$FADH_2$** are coenzymes used to transport activated electrons to the **Electron Transport Chain (ETC).**





- **Carbon Dioxide** is released by exhaling.

Aerobic Respiration

- **How many molecules of CO_2 total are produced during the aerobic metabolism of glucose?**
- **Six:**
  - **2 in the Transition Reaction**
  - **4 in the Krebs Cycle**

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

Glucose — Oxygen — Water — Carbon dioxide

Krebs Cycle

Where does it occur?

What is used?

What energy molecule is produced? What do organisms get rid of?

What are the products entering the ETC?

QUICK CHECK

Krebs Cycle

1. Where does it occur?
   - **Matrix in mitochondria**
2. What is used?
   - **2 Acetyl CoA**
3. What energy molecule is produced? What do organisms get rid of?
   - **4 CO_2, 2 ATP**
4. What are the products that will enter the ETC?
   - **6 NADH, 2 $FADH_2$ via reduction.**

Transition and Krebs Cycle

What role does the transition reaction play in cellular respiration?

How do glycolysis & the Krebs cycle differ in terms of oxygen?

Name the energy molecules produced in the Citric Acid Cycle.

Transition and Krebs Cycle

What role does the transition reaction play in cellular respiration?

1. *Pyruvate (from glycolysis) enters the "matrix" (of the mitochondria) and forms into Acetyl-CoA (a 2 carbon compound).*
2. *Acetyl-CoA goes into the Krebs cycle; NADH enters ETC.*
3. *Carbon Dioxide is released and will be exhaled from the lungs.*

How do glycolysis & the Kreb's cycle differ in terms of oxygen?

1. *Glycolysis is anaerobic (does not require oxygen).*
2. *The Krebs cycle is aerobic (utilizes oxygen).*

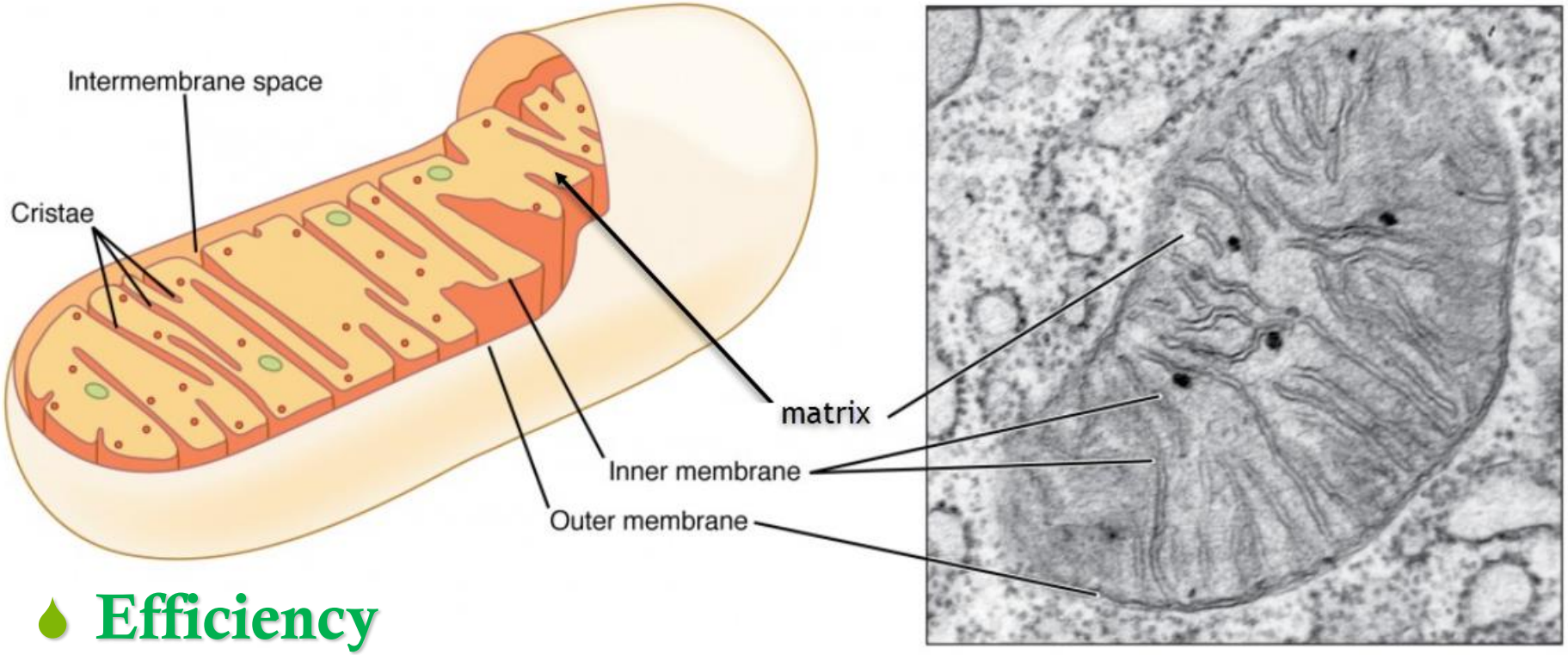
Name the energy molecules produced in the Citric Acid Cycle.

1. *ATP* 2. *NADH* 3. *$FADH_2$*

Stage 3: Electron Transport Chain (ETC) (Oxidative Phosphorylation)

- **Location**
  - **Inner Mitochondrial Membrane (CRISTAE) (eukaryotes)**
  - **Plasma Membrane (prokaryotes)**

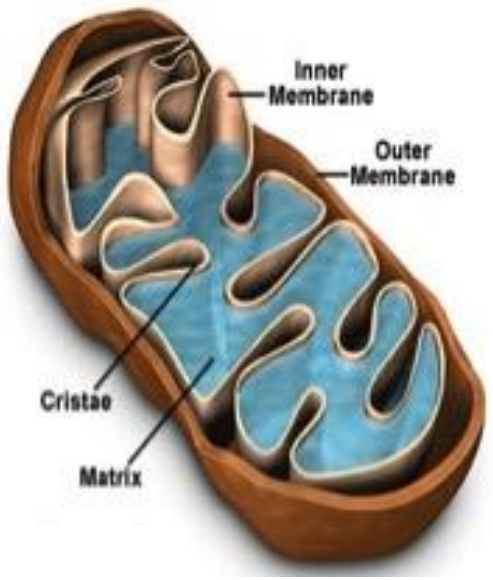
Stage 3: Electron Transport Chain (ETC) (Oxidative Phosphorylation)



- Efficiency
  - Generates up to 32 ATP

Stage 3: Electron Transport Chain (ETC) (Oxidative Phosphorylation)

- Uses the **ETC** and **ATP Synthase** to make **ATP** through **Oxidative Phosphorylation.**
- All **NADH** and **$FADH_2$** is converted to **ATP** during this stage of **cellular respiration**.
- **Majority of ATP** is made in this stage.
- **The final electron acceptor is OXYGEN (oxidation).**
- **When electrons combine with oxygen, WATER is formed.**



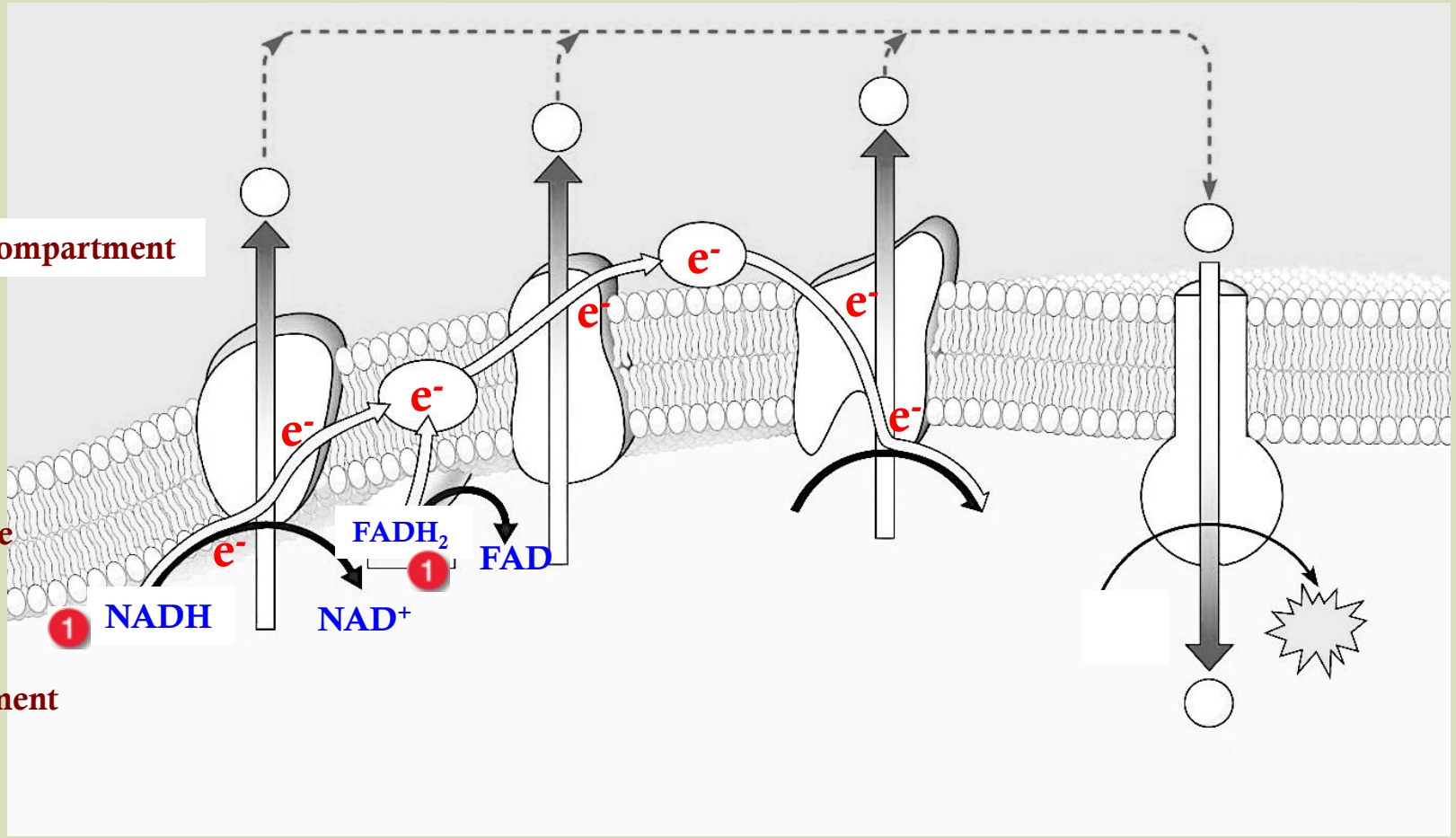
3. Electron Transport Chain (ETC) (Oxidative Phosphorylation)

- **10 NADH** and **2 $FADH_2$** deliver electrons to **electron transport chain (OXIDATION).**
- Electron transport sets up **H^+ ion gradients.**
- The energy released by the downhill fall of electrons from NADH and $FADH_2$ to Oxygen is used to **phosphorylate ADP → ATP.**

(completes Oxidative Phosphorylation)

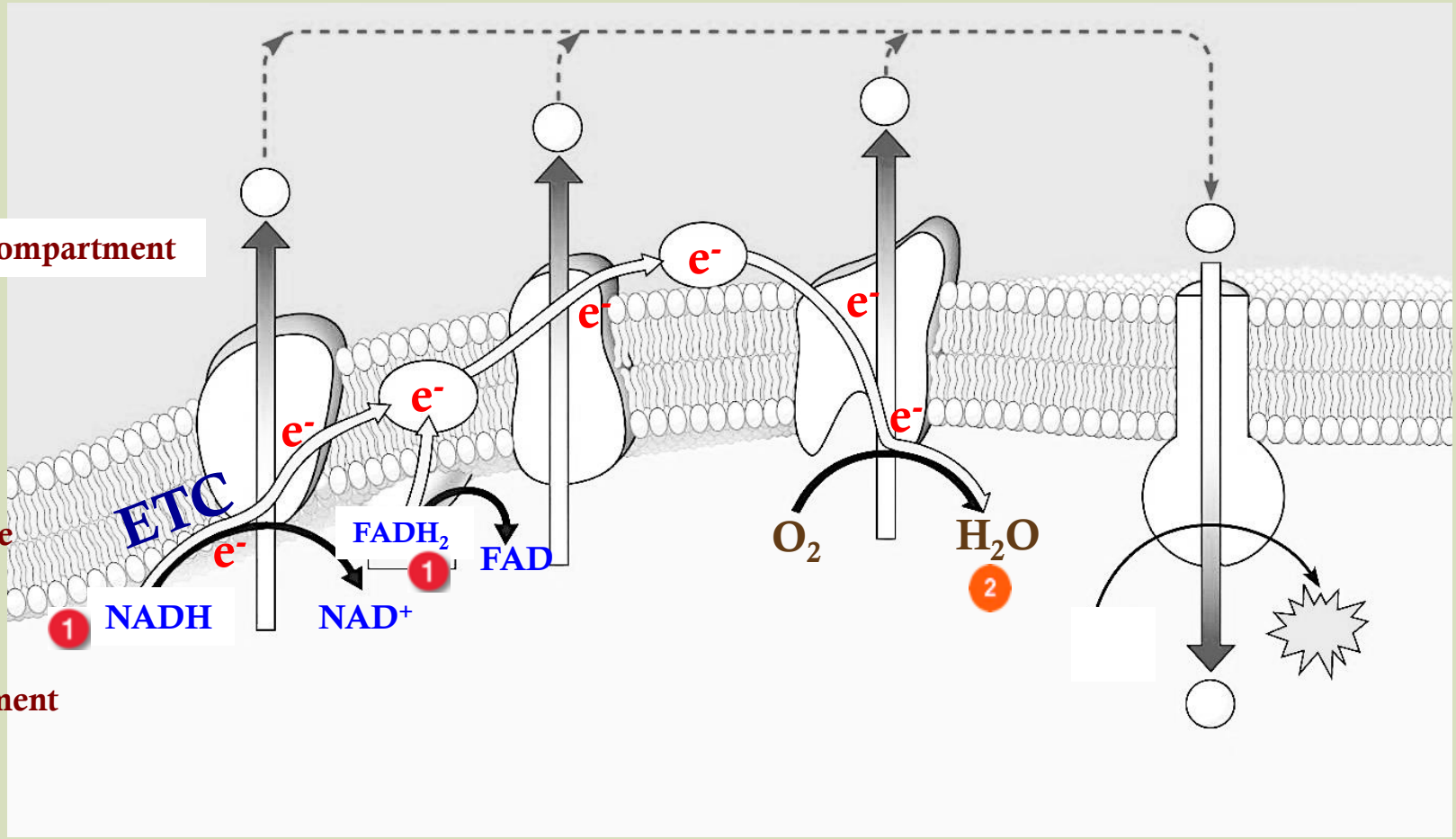
- Flow of **H^+** down gradients through **ATP Synthase** powers **ATP formation (Chemiosmosis).**

Steps of the Electron Transport Chain



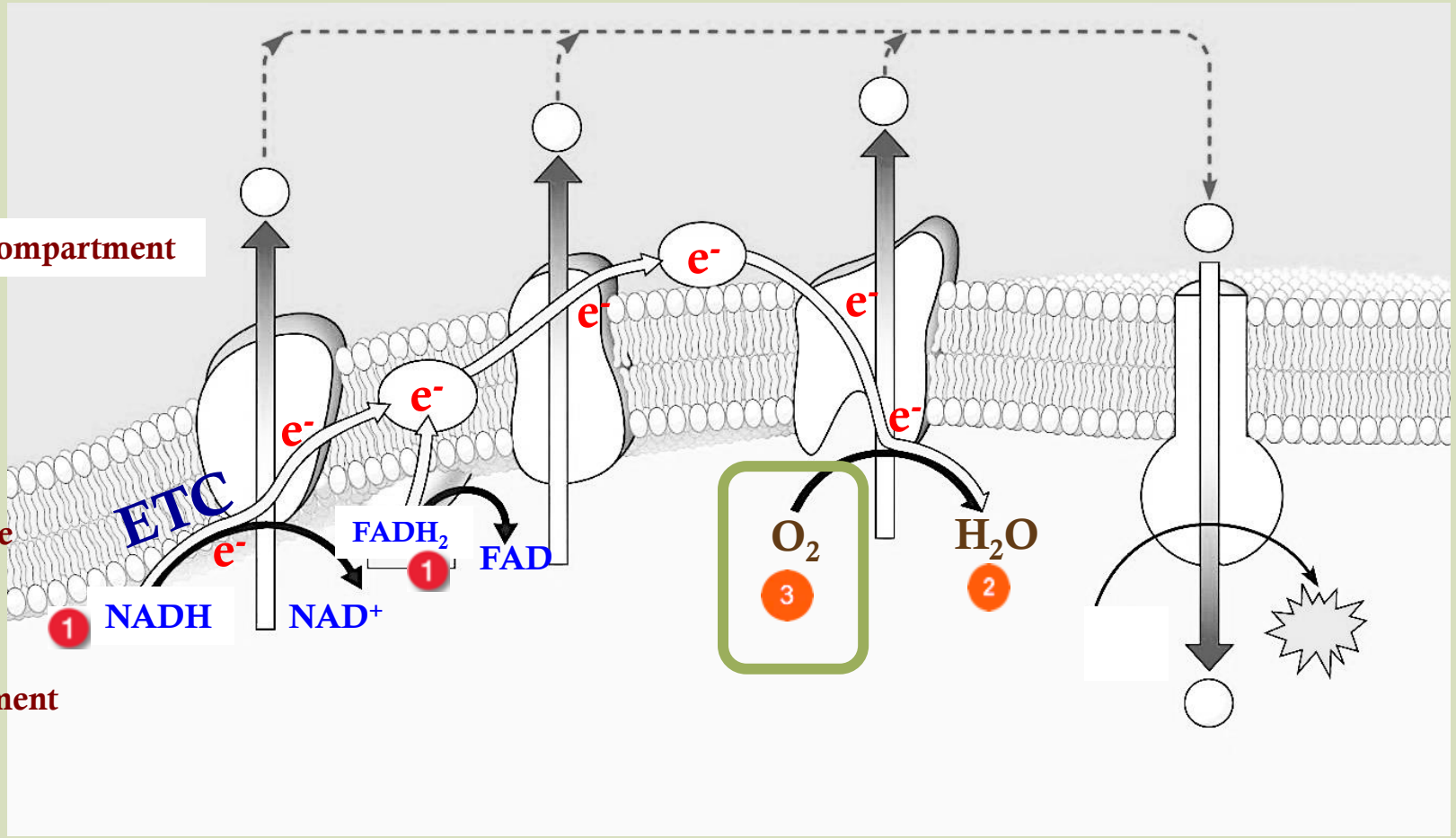
1 The high-energy electrons from **NADH** and **$FADH_2$** are passed along the electron transport chain, from one protein to the next, forming **NAD+** and **FAD** **(oxidation)**.

Steps of the Electron Transport Chain



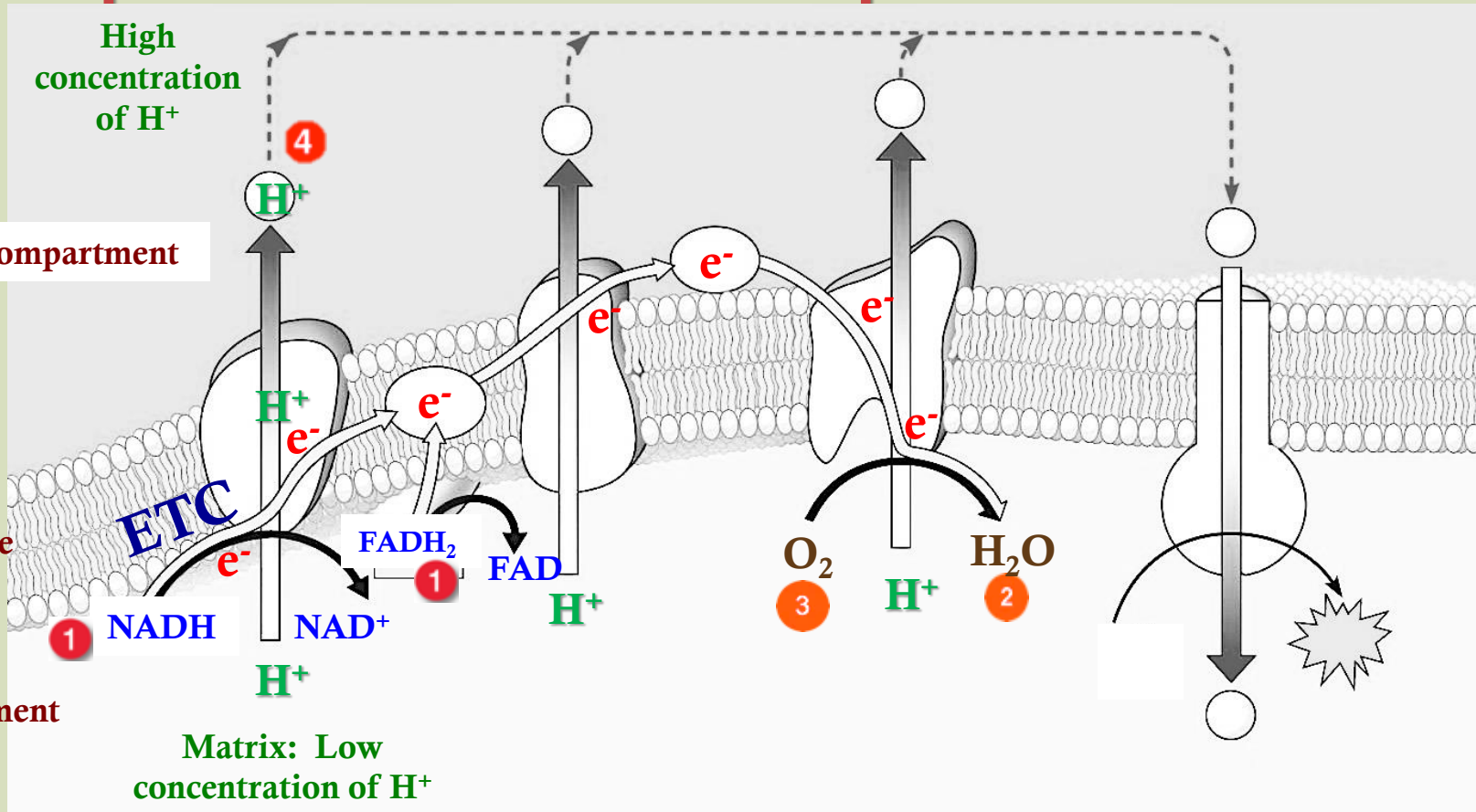
2 At the end of the electron transport chain, the electrons & Hydrogen ions will be combined with **oxygen** to form **water**. ["oxidative"]

Steps of the Electron Transport Chain



3 Oxygen is the final electron acceptor. Oxygen is essential for getting rid of low energy electrons and hydrogen ions.

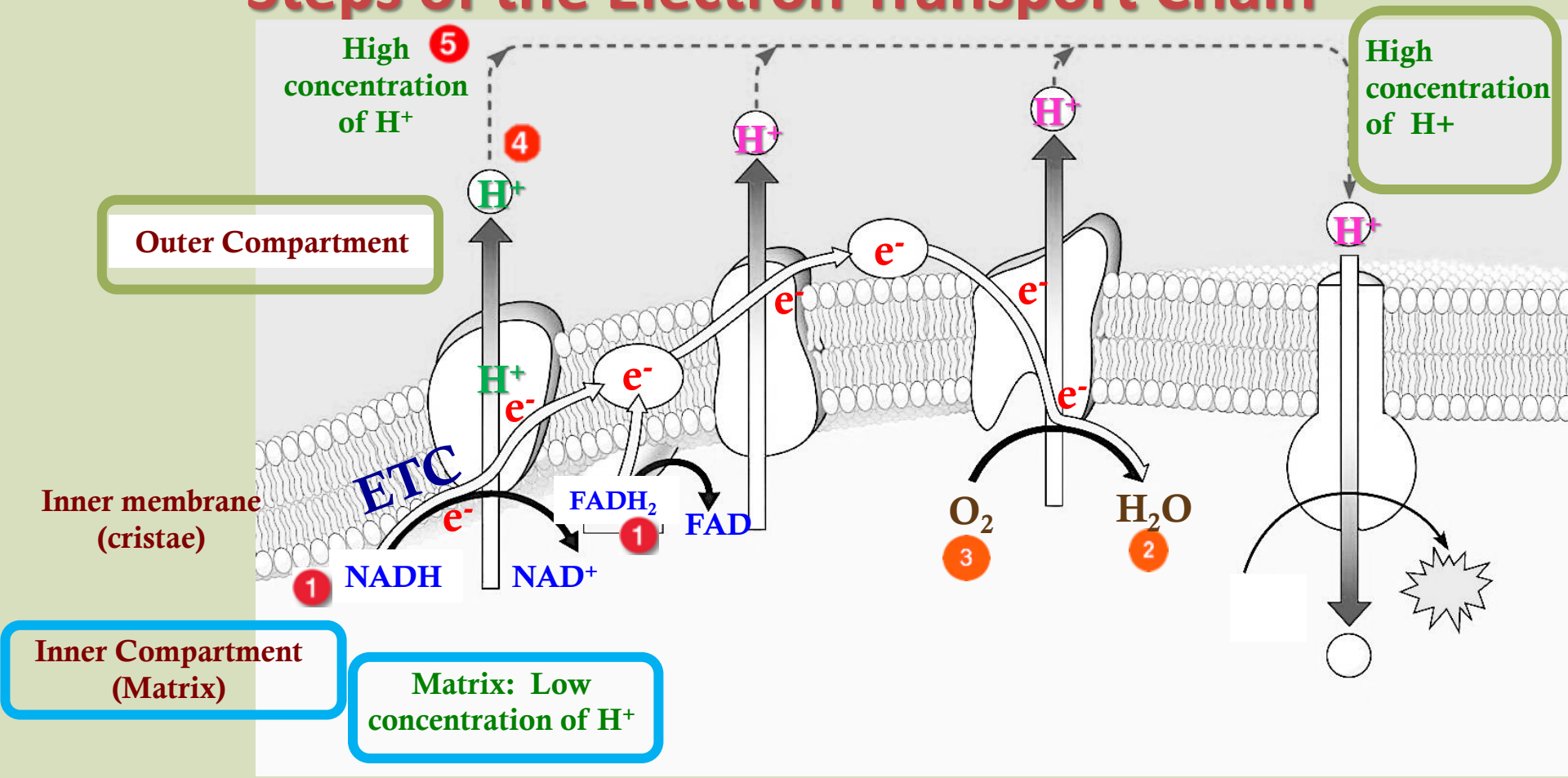
Steps of the Electron Transport Chain



4

- As these electrons move down the electron transport chain, they release **energy**, which is used to pump **hydrogen ions** across the membrane from the **matrix** to the **Outer Compartment**.
- The hydrogen ions are pumped **against** the concentration **gradient** from an area of **low** concentration to an area of **high** concentration in the outer compartment (in the matrix).

Steps of the Electron Transport Chain

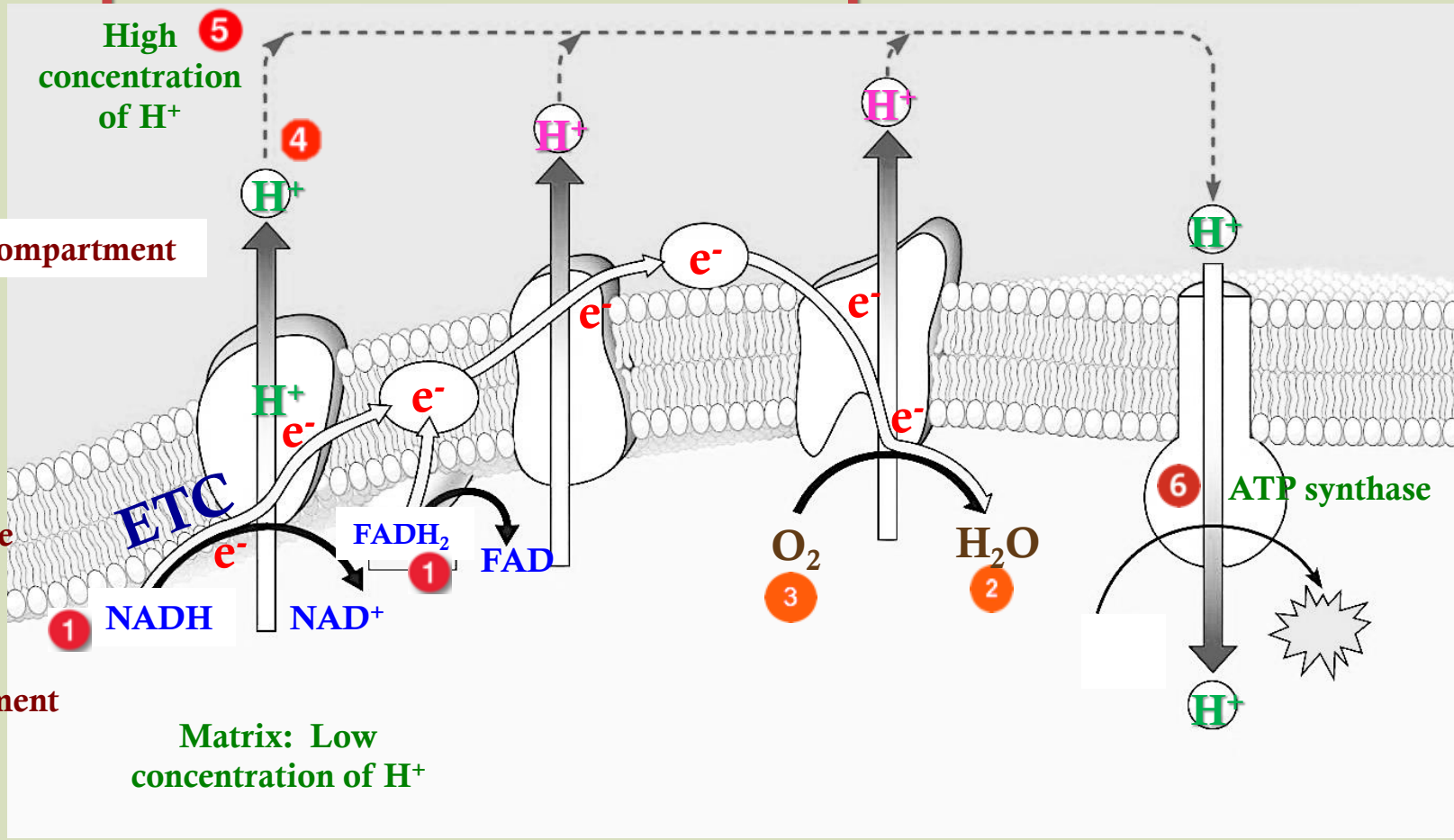


5 A concentration **gradient** has now been established.

There is a high concentration of hydrogen in the **outer** compartment.

and a low concentration in the **matrix**.

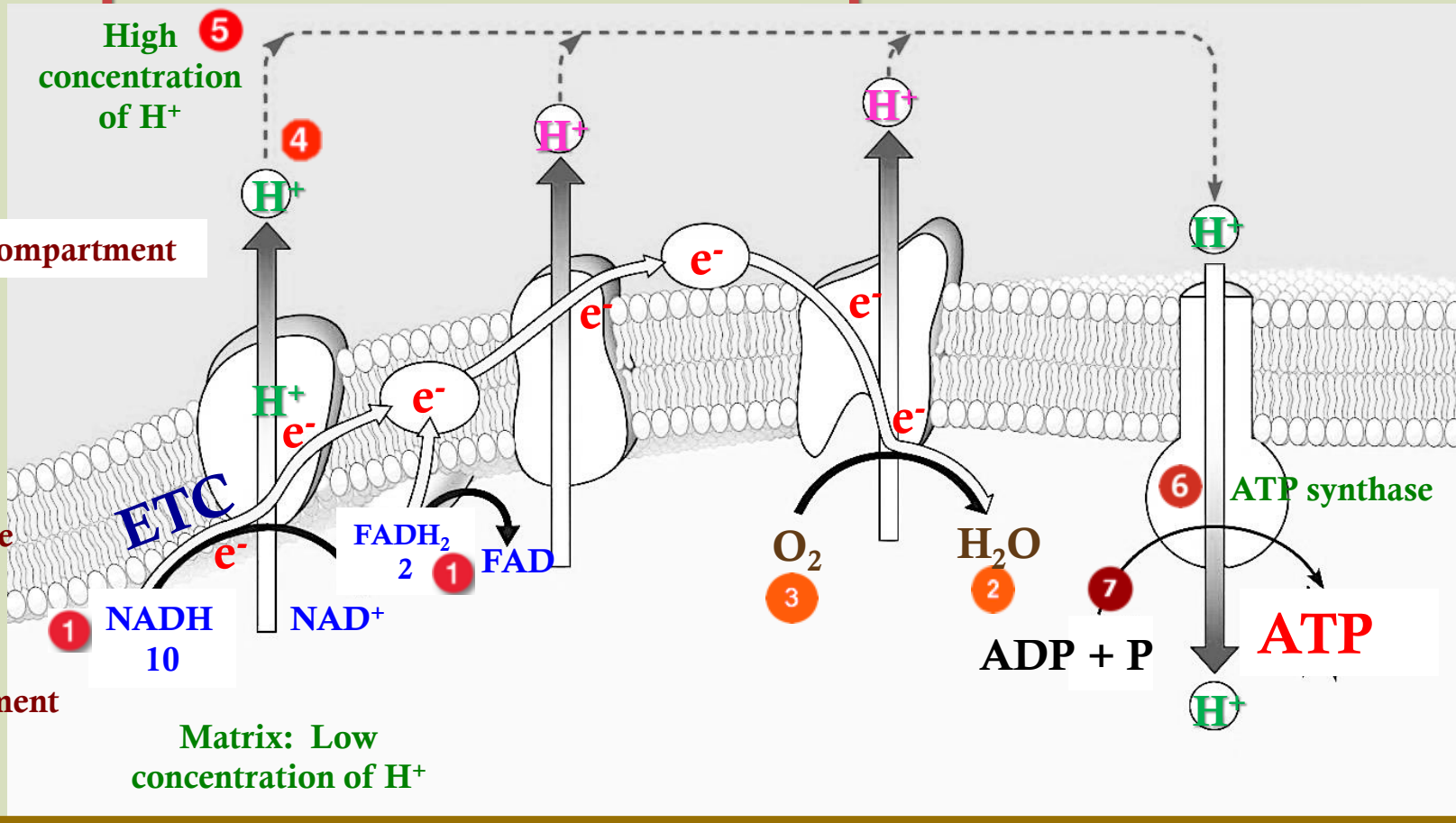
Steps of the Electron Transport Chain



6 Also embedded in the mitochondrial membranes are enzymes called **ATP synthases**.

Hydrogen ions flow through ATP synthase back the area of **low** concentration in the **matrix** .

Steps of the Electron Transport Chain

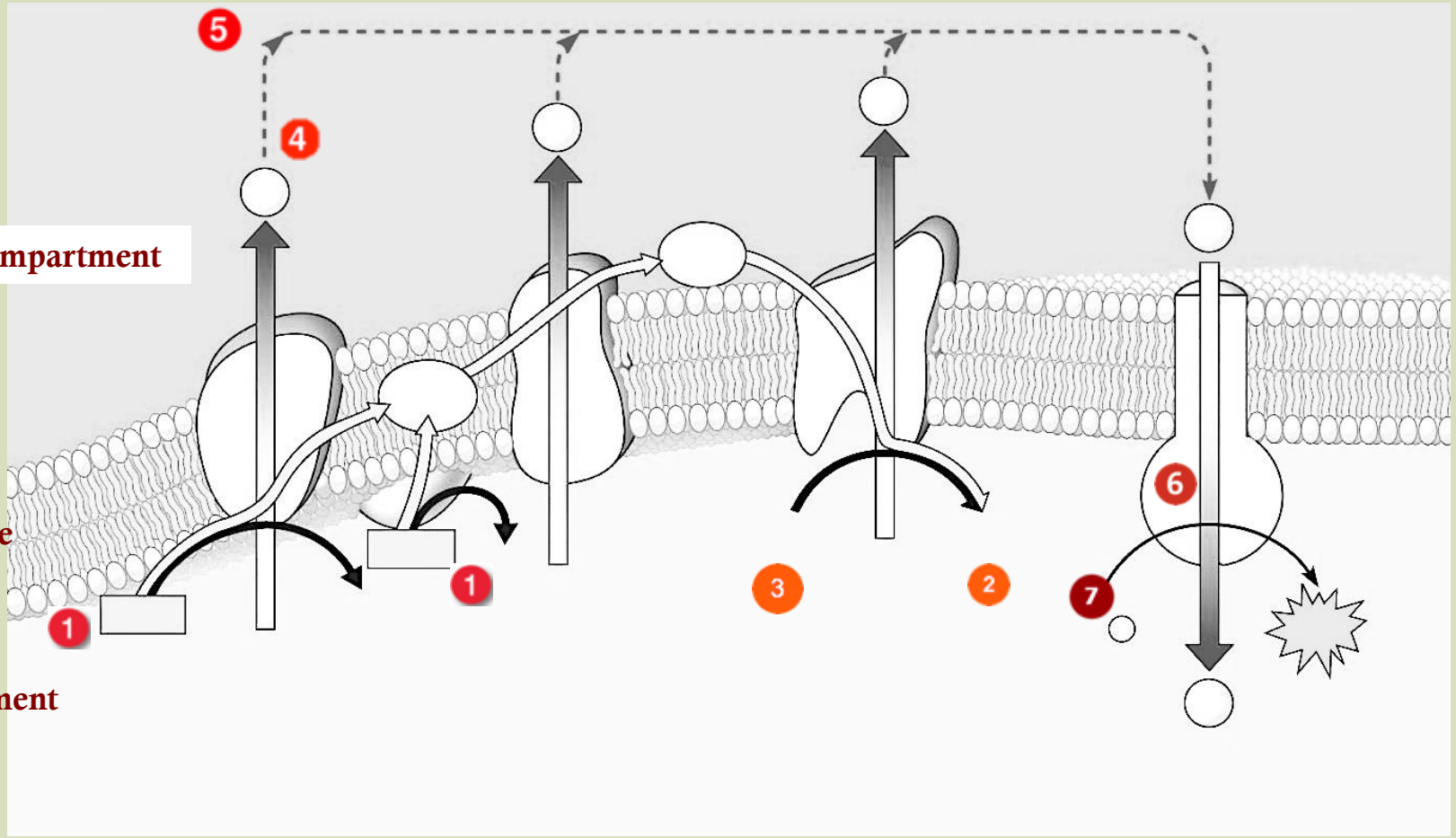


7 As the hydrogen flows through ATP synthase, it spins like a rotor.

Each time it rotates, a phosphate is attached to ADP to form ATP. ("phosphorylation")

TRY IT

Steps of the Electron Transport Chain



Can You Explain each step in the Diagram?
(*If not, go back & review*)

Electron Transport Chain (ETC)

Where does it occur?

What molecules are used?

What molecule & energy molecule is produced?

What are the oxidized products?

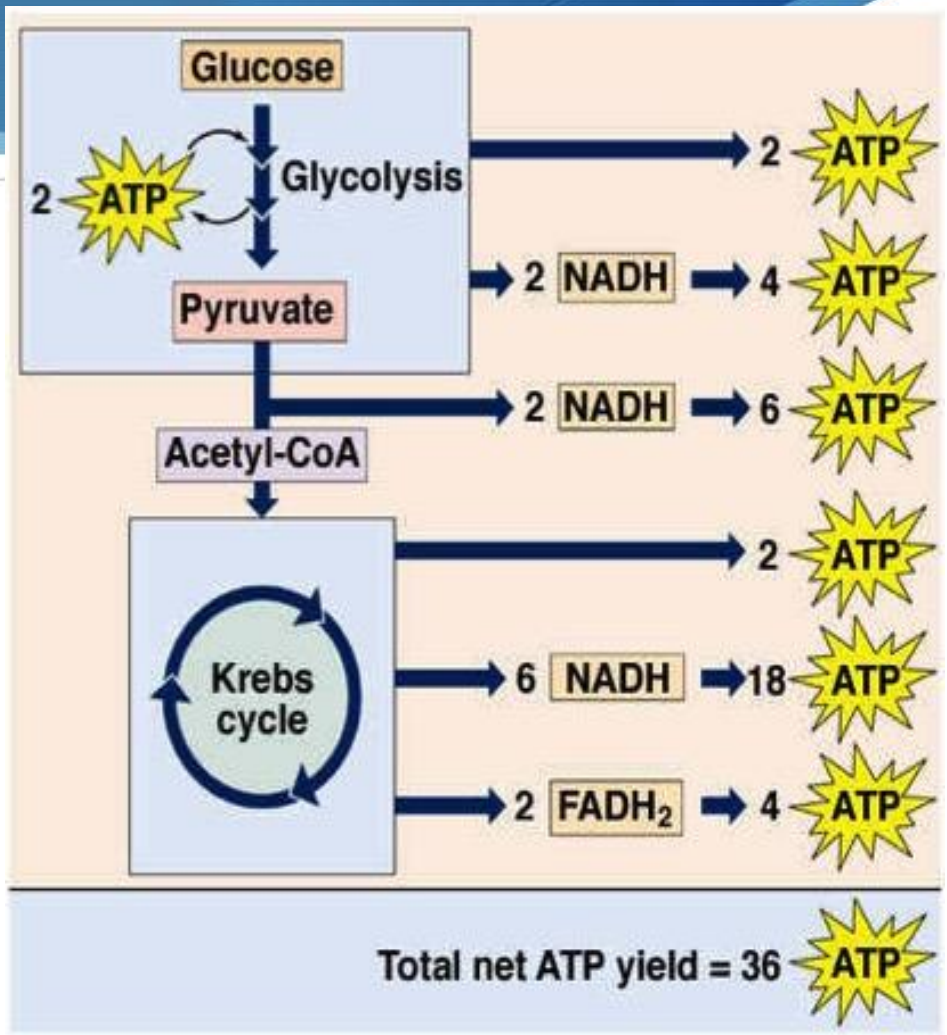
Electron Transport Chain (ETC)

1. Where does it occur?
   - **Cristae (membranes) in mitochondria**
2. What molecules are used?
   - **H+ from NADH and $FADH_2$, O_2**
3. What molecule and energy molecule is produced?
   - **34 ATP and H_2O molecules**
4. What are the oxidized products?
   - **NAD^+, FAD^{+2}**

Summary of Energy Harvest (per molecule of Glucose)

Output:

1) **NADH from Glycolysis:**
   - 2 ATP from each at ETC
   - Some energy is used initially to import these NADH from the cytoplasm into the mitochondria
2) **NADH from Transition Reaction + Krebs Cycle:**
   - 3 ATP from each at ETC
3) **$FADH_2$ from Krebs Cycle:**
   - 2 ATP from each at ETC



Summary of Energy Harvest (per molecule of Glucose)

- **Glycolysis**
  - 2 ATP
  - 2 NADH → 4 ATP
- **Transition Reaction**
  - 2 NADH → 6 ATP
- **Kreb's Cycle**
  - 2 ATP
  - 6 NADH → 18 ATP
  - 2 $FADH_2$ → 4 ATP

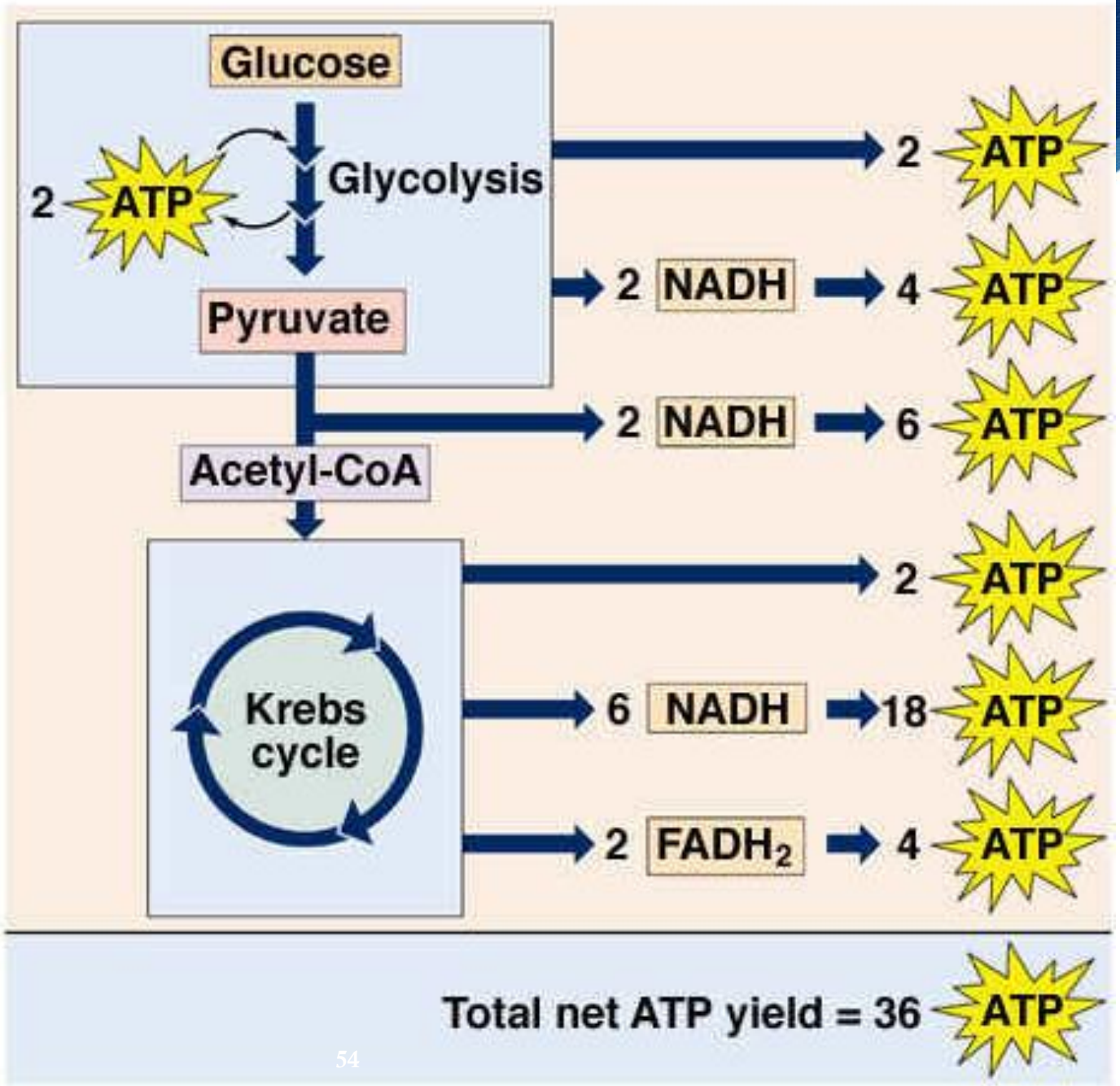
Electron Transport Chain

4 ATP + 6 ATP + 18 ATP + 4 ATP = **32 ATP**

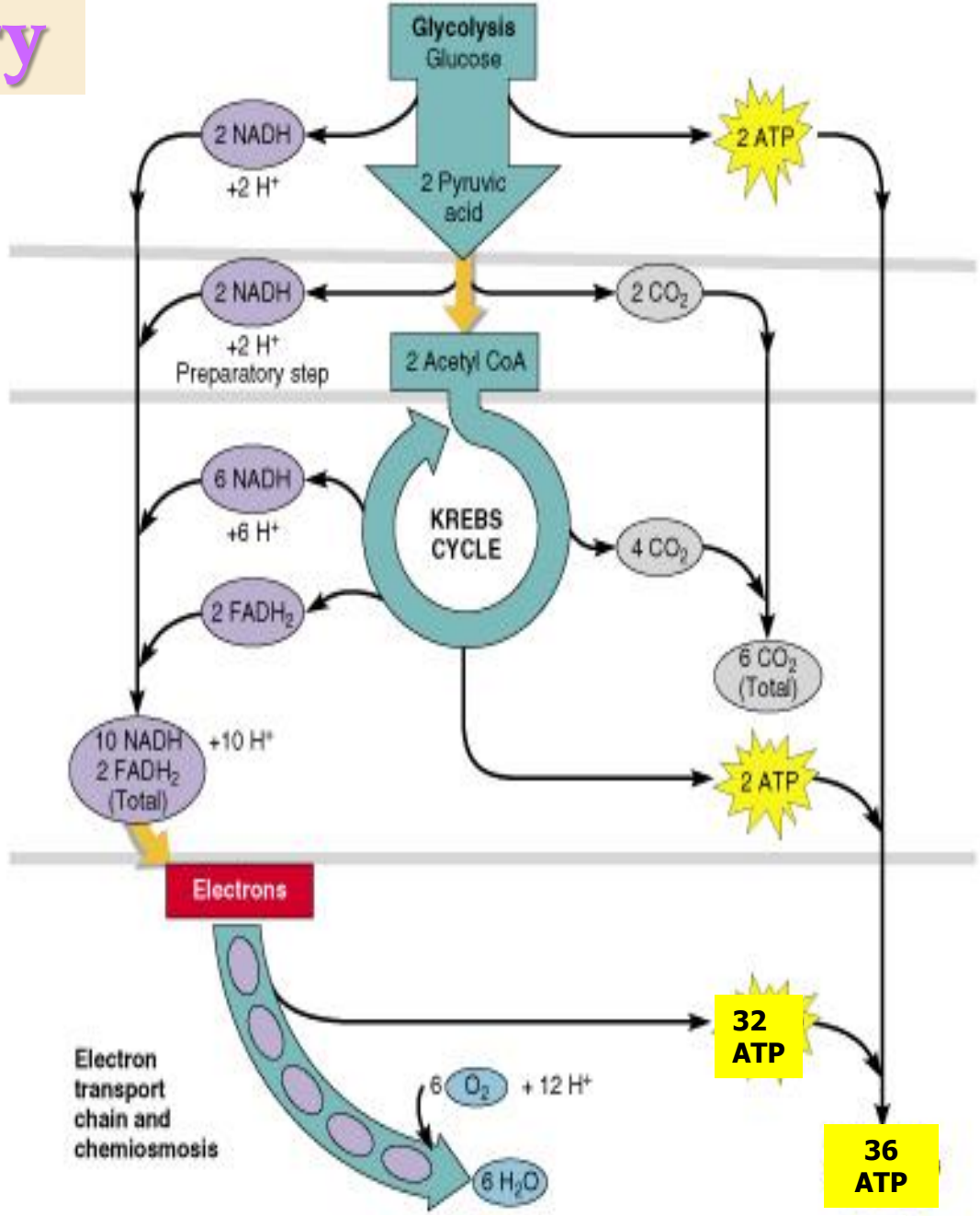
Total in Aerobic Respiration

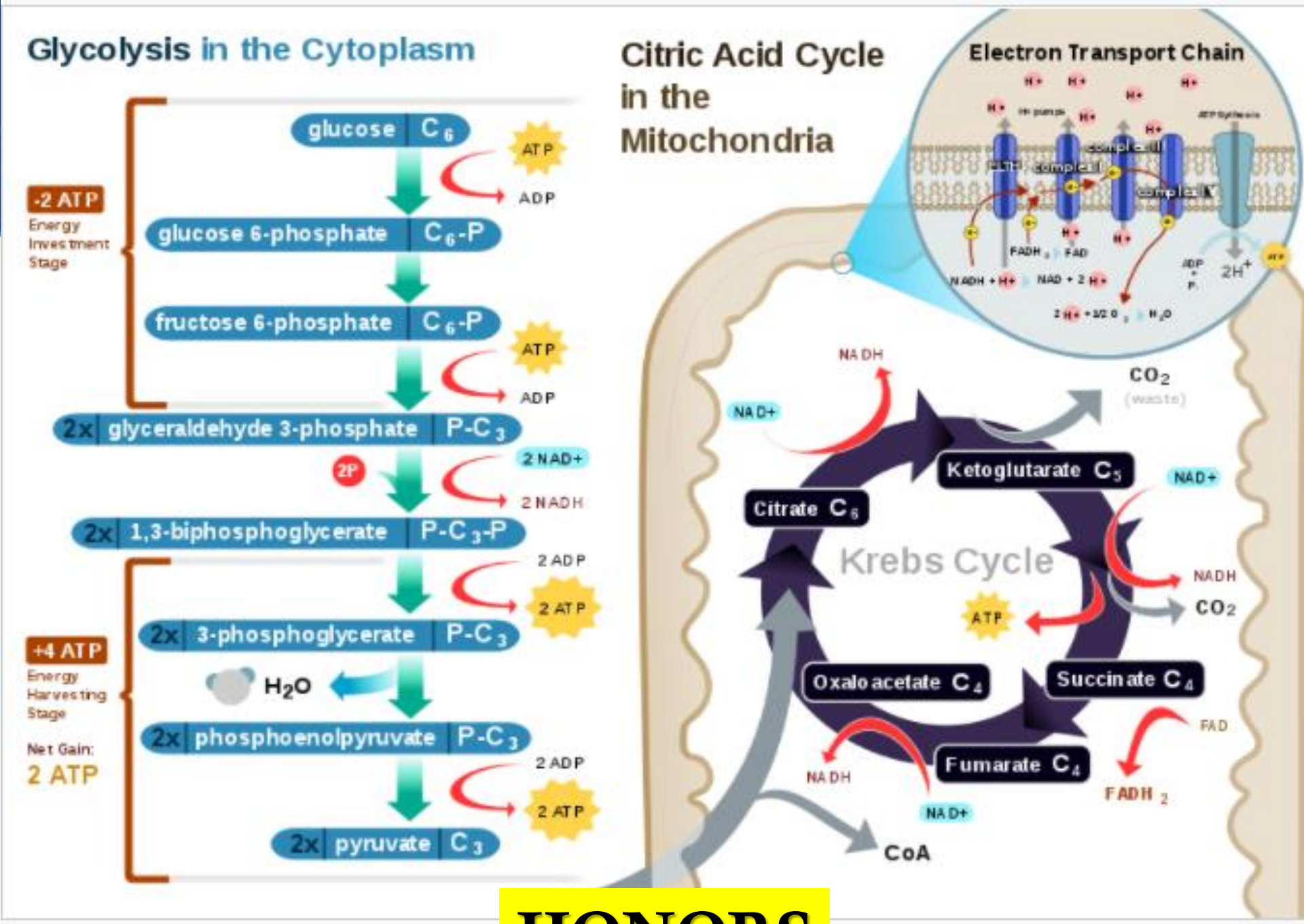
36 ATP

ATP Theoretical Yield



Summary

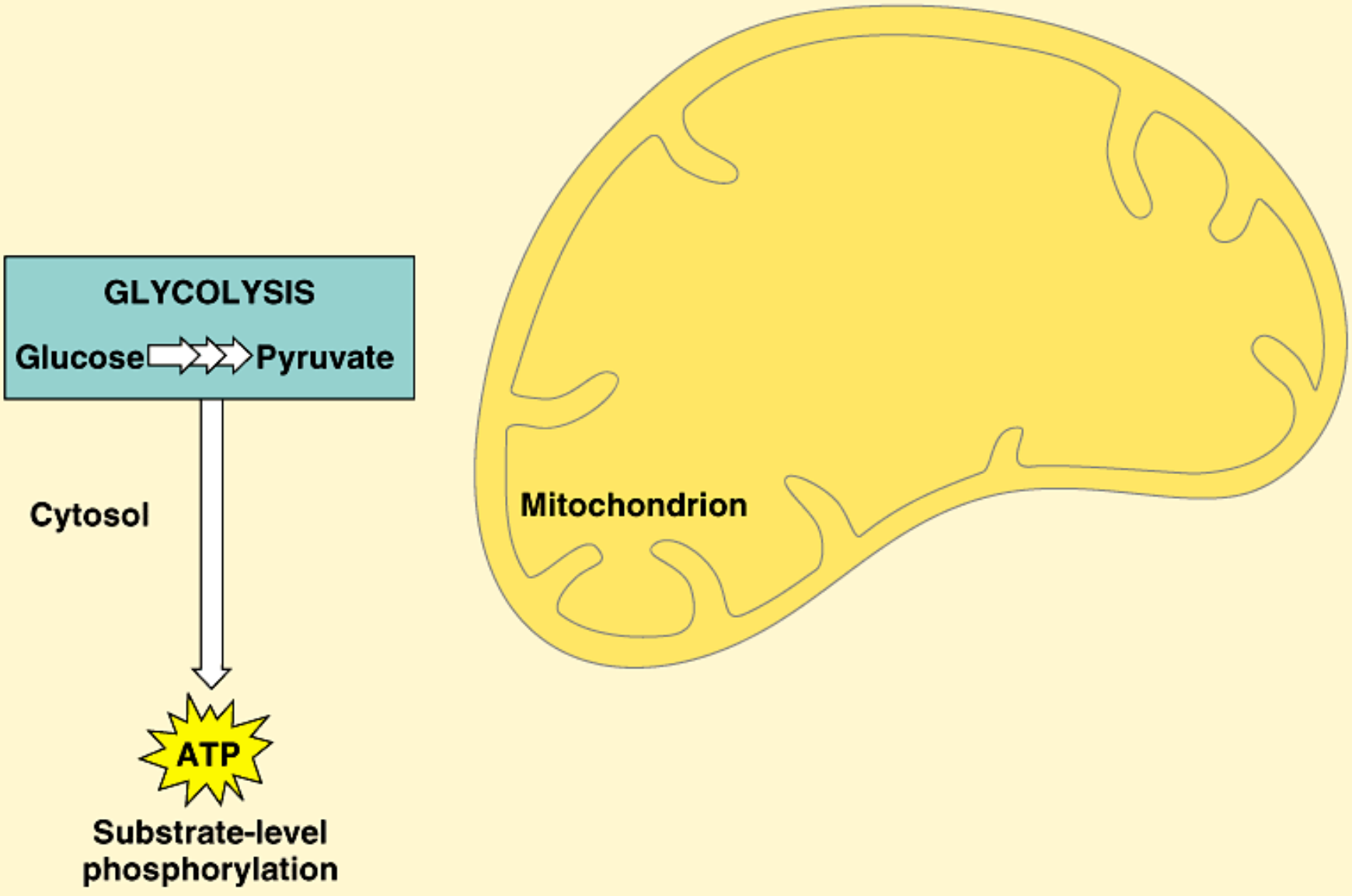

Glycolysis
Glucose
2 NADH
+2 H+
2 Pyruvic acid
2 ATP
2 NADH
+2 H+
Preparatory step
2 CO2
2 Acetyl CoA
6 NADH
+6 H+
KREBS CYCLE
4 CO2
2 FADH2
6 CO2 (Total)
10 NADH
2 FADH2
(Total)
+10 H+
2 ATP
Electrons
32 ATP
Electron transport chain and chemiosmosis
6 O2
+ 12 H+
6 H2O
36 ATP



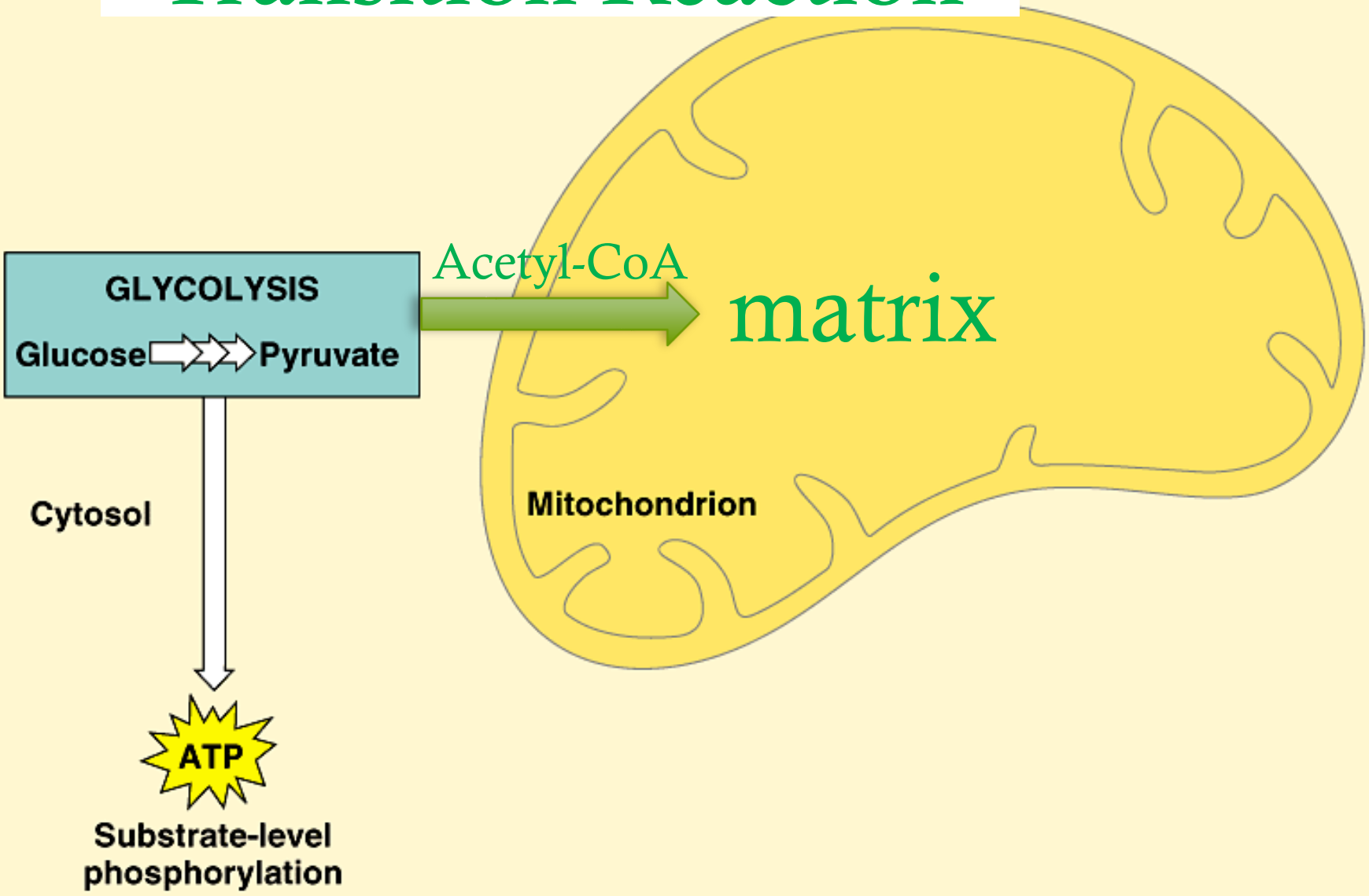
HONORS

Typical eukaryotic cell

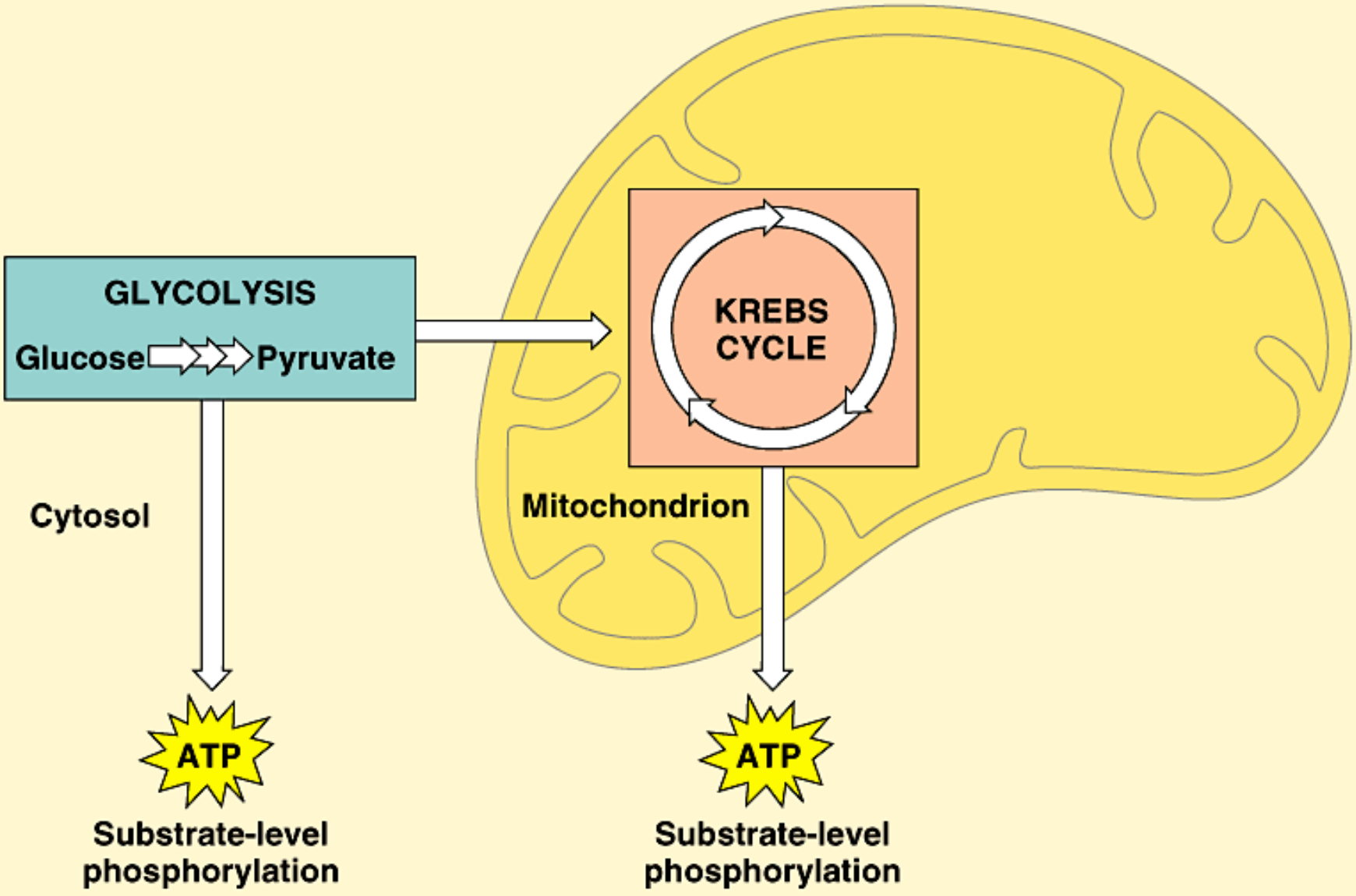
Cellular Respiration Review



Transition Reaction



Cellular Respiration Review



Cellular Respiration Review

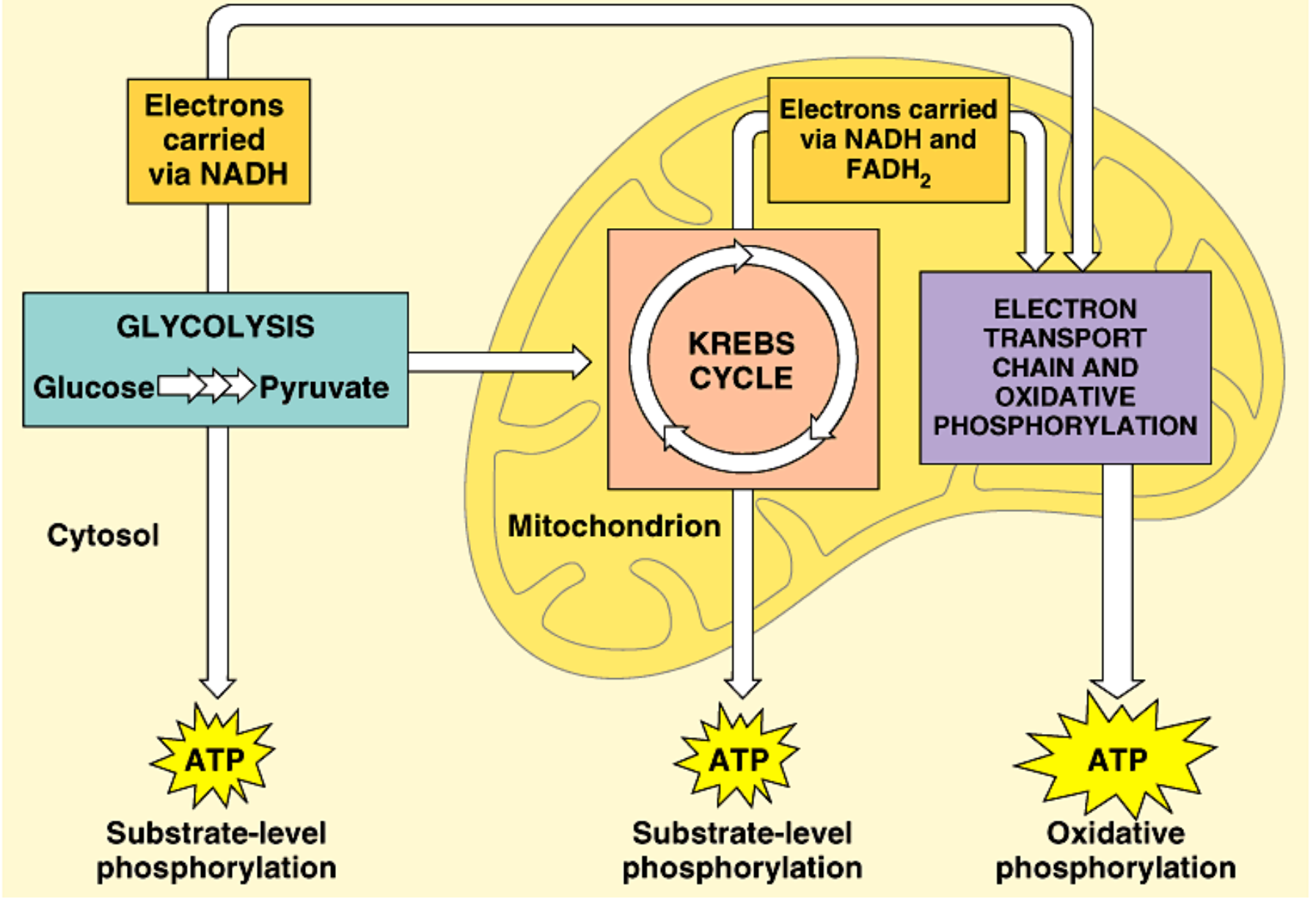
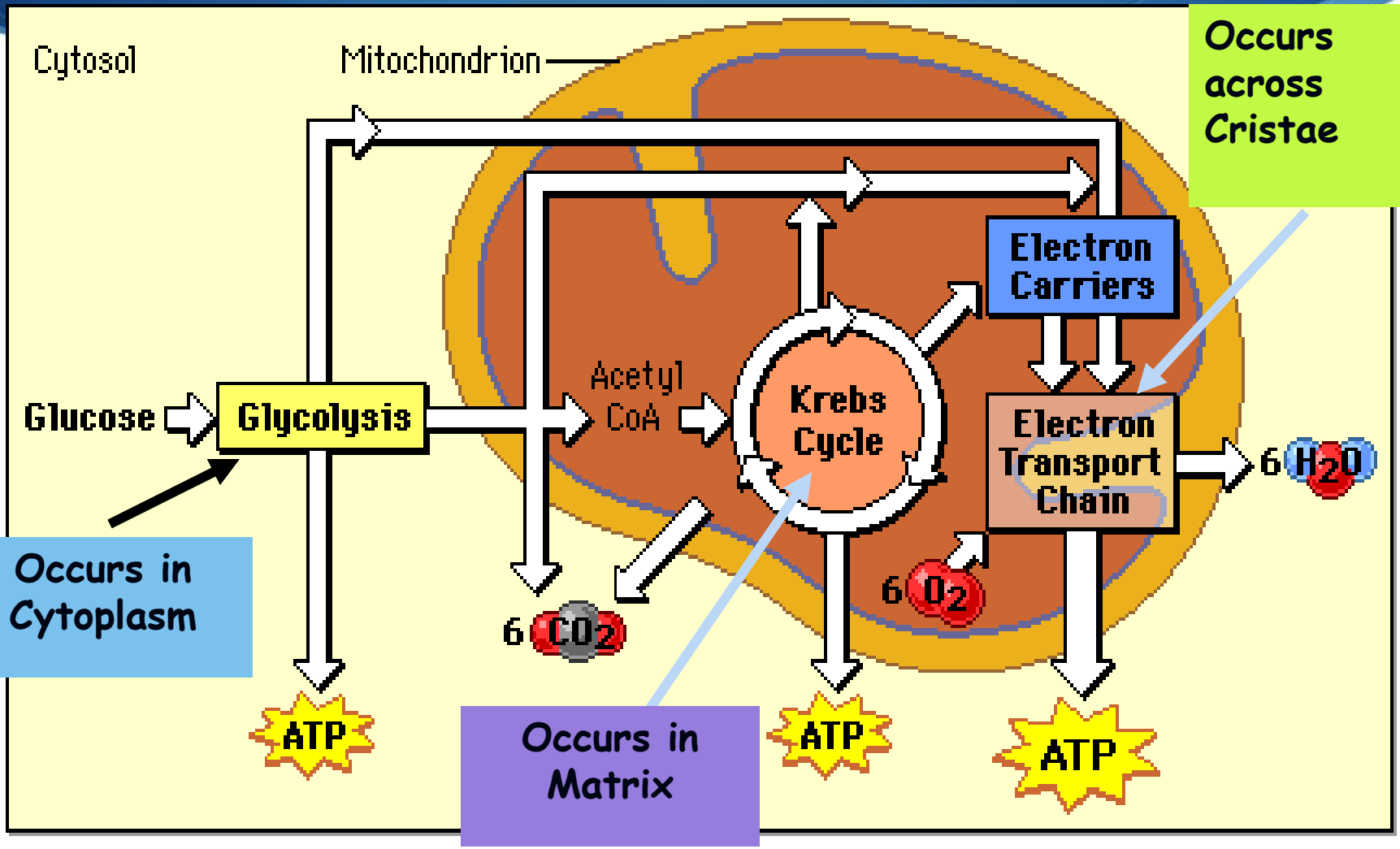


Diagram of Cellular Respiration



Summary of the 3 Major Stages of Cellular Respiration:

Pathway	Eukaryote	Prokaryote

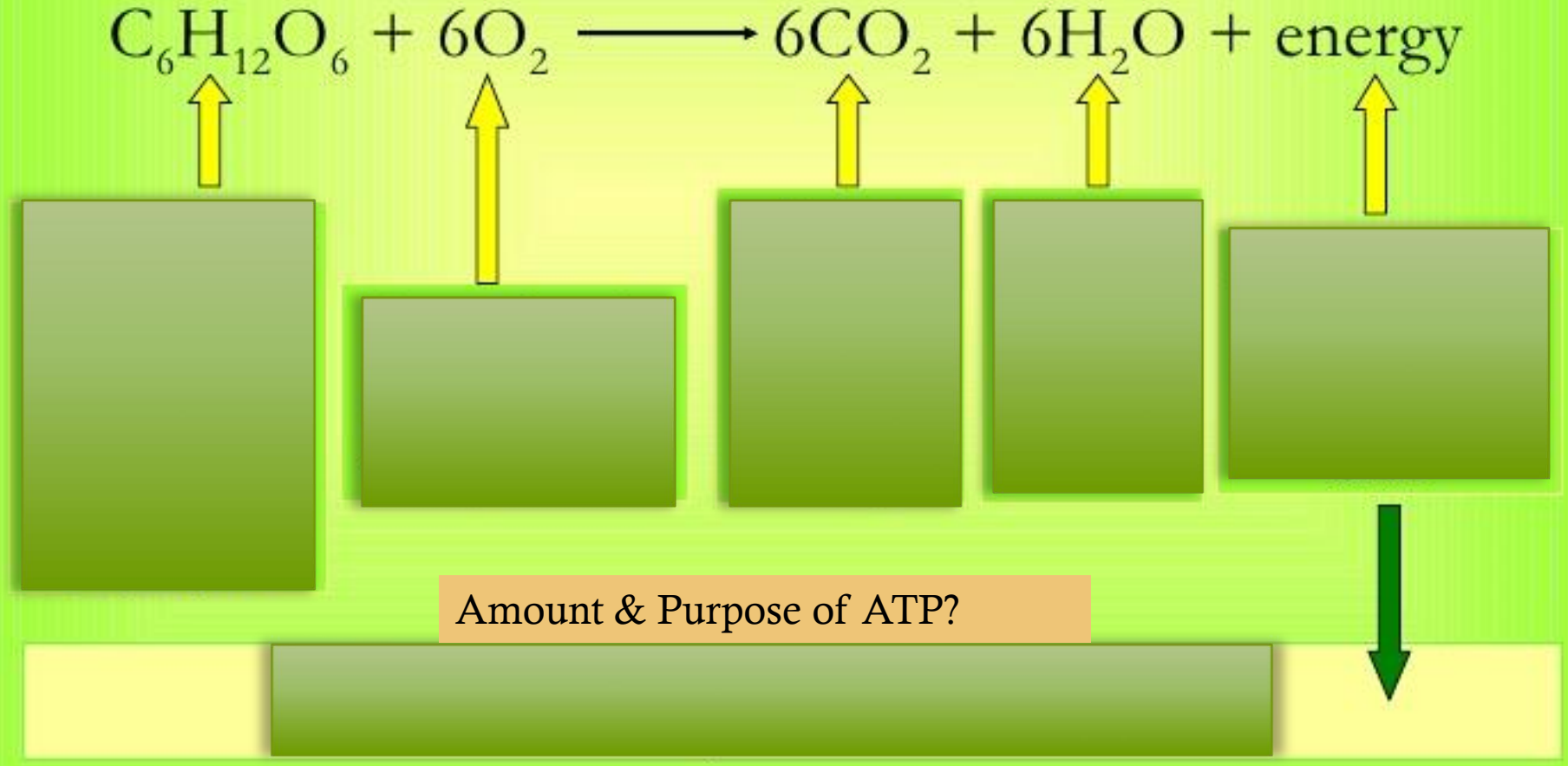
Summary of the 3 Major Stages of Cellular Respiration:

Pathway	Eukaryote	Prokaryote
Glycolysis	Cytoplasm	Cytoplasm
Krebs cycle	Mitochondrial matrix	Cytoplasm
ETC (Electron Transport Chain)	Mitochondrial inner membrane	Plasma membrane

TRY IT

Cellular Respiration Equation

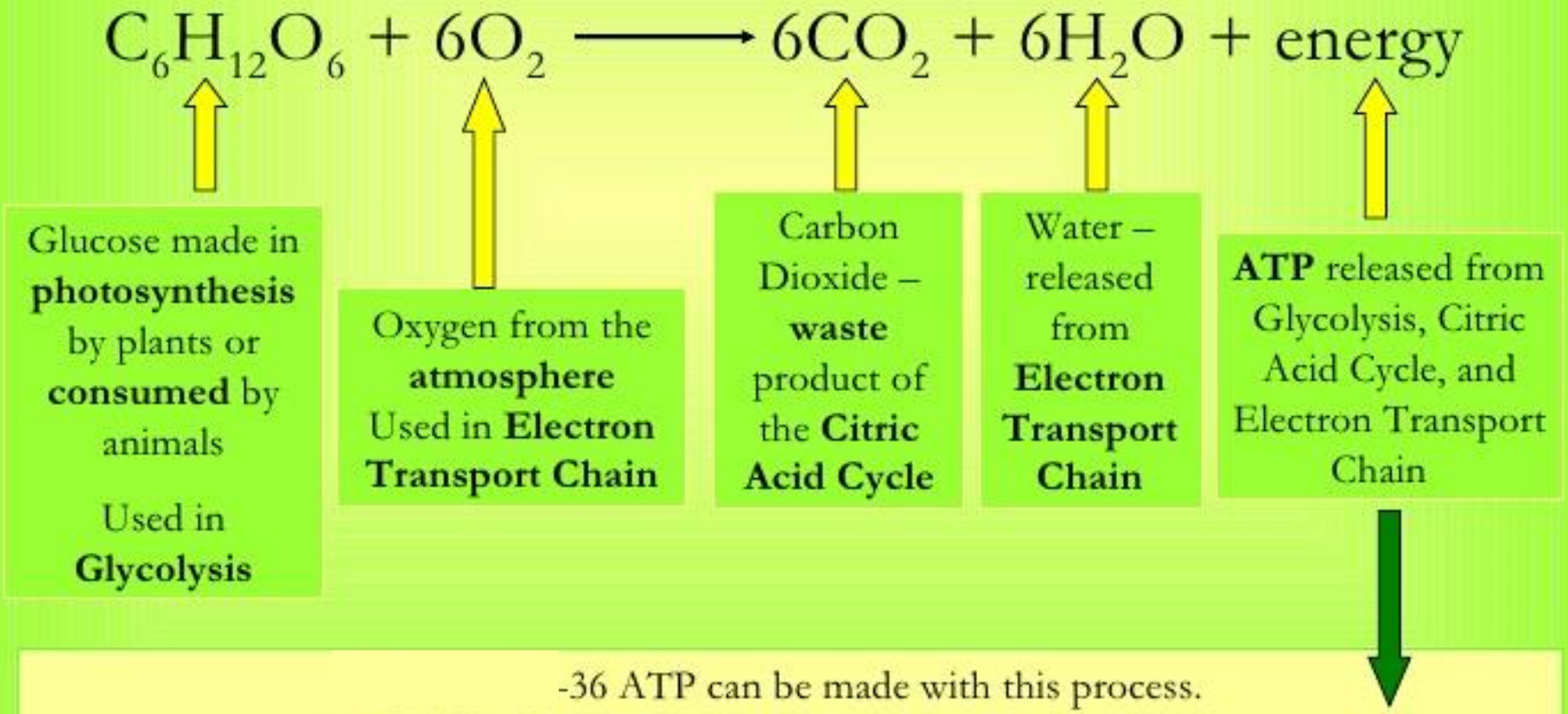
Name each molecule. Tell where it comes from, and name the stage it appears?



Amount & Purpose of ATP?

TRY IT

Cellular Respiration Equation



-36 ATP can be made with this process.
This ATP can be used by the cells for cellular metabolism.

Identifying the Stages of Cellular Respiration

Identify the stage of cellular respiration for each of the following:

- Produces 32 ATP molecules …
- Creates four ATP molecules, but gains only two overall …
- Gives off carbon dioxide …
- Gives off water …
- Produces two ATP molecules total …
- Converts pyruvate to Acetyl-CoA …
- Takes place in the matrix of the mitochondria …
- Produces NADH from NAD+ …
- Takes place in the cytoplasm in eukaryotes …
- Produces $FADH_2$ for the ETC …

Identifying the Stages of Cellular Respiration

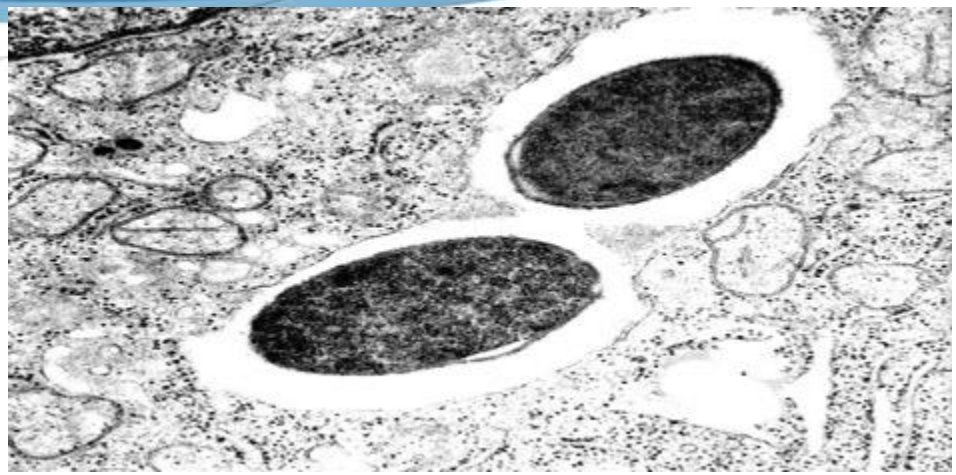
Identify the stage of cellular respiration for each of the following:

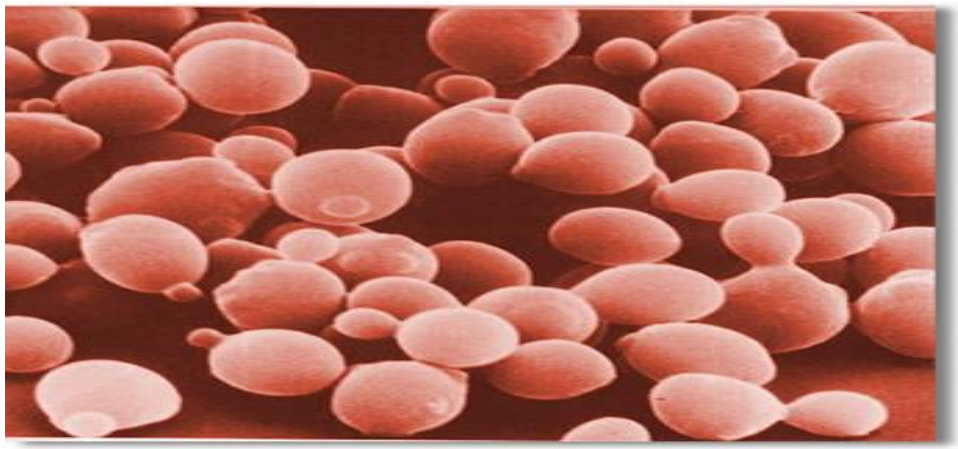
- Produces 32 ATP molecules … electron transport chain
- Creates four ATP molecules, but gains only two overall … glycolysis
- Gives off carbon dioxide … citric acid cycle (Krebs cycle)
- Gives off water … electron transport chain
- Produces two ATP molecules total … citric acid cycle
- Converts pyruvate to Acetyl-CoA … transition reaction
- Takes place in the matrix of the mitochondria … transition reaction & Krebs
- Produces NADH from NAD+ … glycolysis, transition reaction, Krebs cycle
- Takes place in the cytoplasm in eukaryotes … glycolysis & fermentation
- Produces $FADH_2$ for the ETC … Krebs cycle

Anaerobic Processes

- **FERMENTATION**
- **No Oxygen** is required
- **Glycolysis** is the first step
- Some bacteria and yeast are examples of "anaerobes"
- **Net gain = 2 ATP**

per glucose molecule





Fermentation

- **Pyruvate** can be metabolized by:
  - **Alcoholic Fermentation (AF)**
    - produces ethyl alcohol and CO_2
    - In bacteria and yeast cells
  - **Lactic Acid Fermentation (LAF)**
    - **LAF** produces lactic acid. It can build up in muscles during strenuous exercise and cause burning and soreness.
    - In bacteria and muscles
- **Glycolysis is first part of Fermentation**

Lactic Acid Fermentation

- Cheese & Yogurt

- Accumulation of **lactic acid** after rigorous exercise causes fatigue and sore muscles.
- **Lactic acid** will eventually be converted back to **pyruvate** in the liver once oxygen is available.

Alcohol Fermentation

- Baking
- Brewing
- Winemaking

Reactants

Glucose

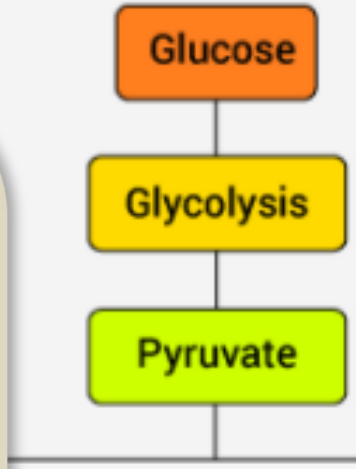
Anaerobic respiration

Alcohol fermentation

Products

2 ethanol + 2 ATP + CO_2

Anaerobic & Aerobic Cell Respiration



No oxygen is present.

Which type of respiration is it?

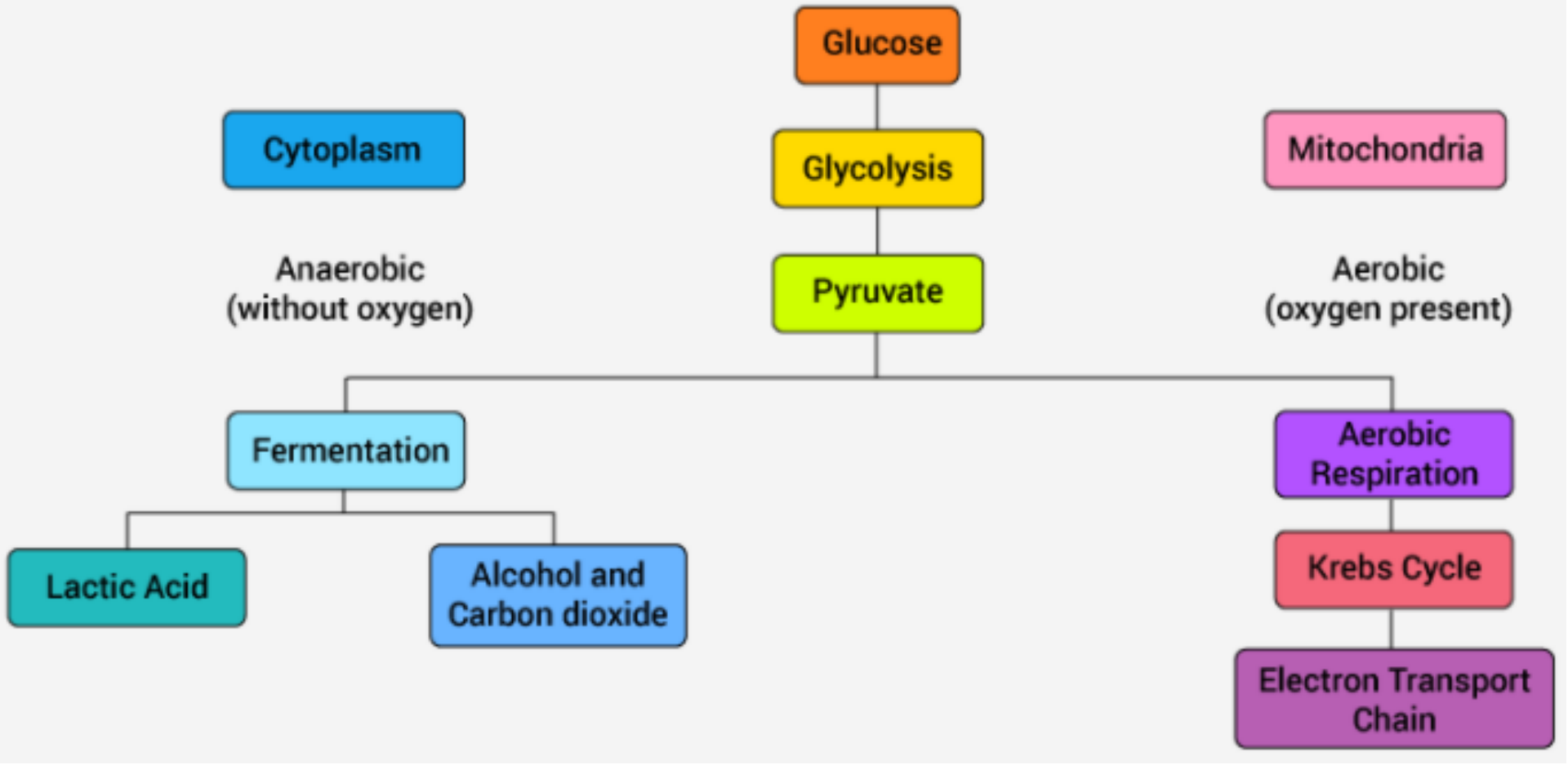
Where does it take place?

What reactions are involved?

Oxygen is present.

Same Questions …

Anaerobic & Aerobic Cell Respiration



Comparison of Cellular Respiration Processes

QUICK CHECK

Respiration Process	Where Process Occurs	Net Gain of ATP Per Glucose
Anaerobic: Glycolysis & Fermentation		
Aerobic: Krebs Cycle & ETC		

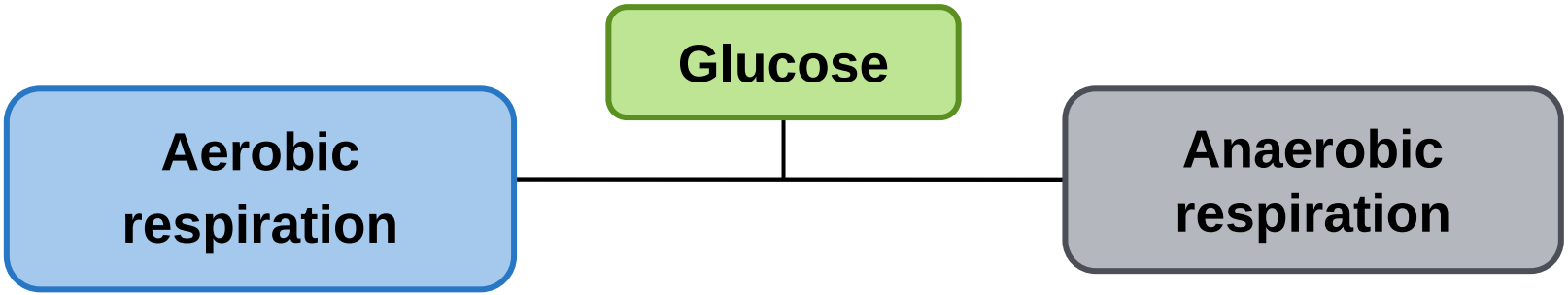
Comparison of Cellular Respiration Processes

QUICK CHECK

Respiration Process	Where Process Occurs	Net Gain of ATP Per Glucose
Anaerobic: Glycolysis & Fermentation	Cytoplasm	2 ATP
Aerobic: Krebs Cycle & ETC	Mitochondria	2 ATP + 32 ATP 34 ATP

QUICK CHECK

ATP in Cellular Respiration



(**Oxygen ?**)

Glycolysis: ___ ATP

_____**cycle**: ___ ATP

_____ _____ _____ **ETC**

(up to ___ ATP)

Total = ___ ATP

(**oxygen ?**)

Glycolysis: ___ ATP

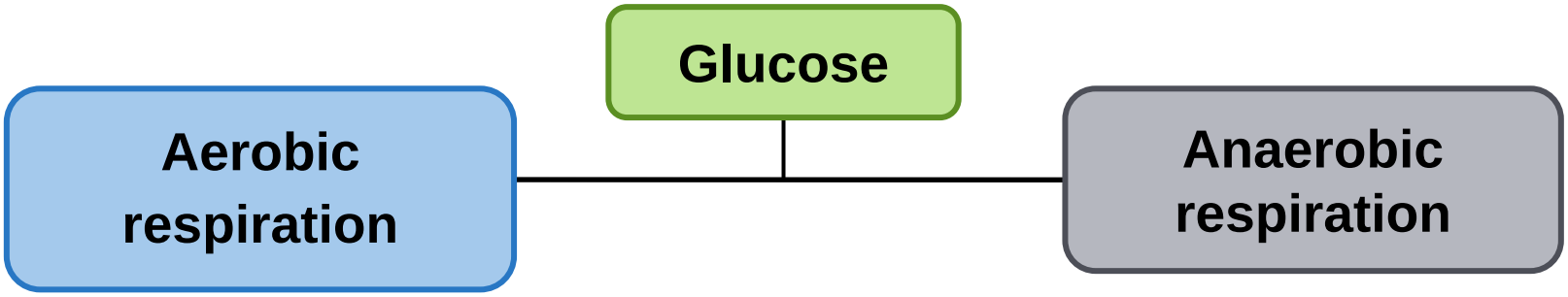
_____: __ ATP

(lactic acid or alcohol)

Total = ___ ATP

QUICK CHECK

ATP in Cellular Respiration



(**Oxygen present**)

Glycolysis: 2 ATP

Citric acid cycle: 2 ATP

Electron transport chain ETC

(up to 32 ATP)

Total = 36 ATP

(**No oxygen present**)

Glycolysis: 2 ATP

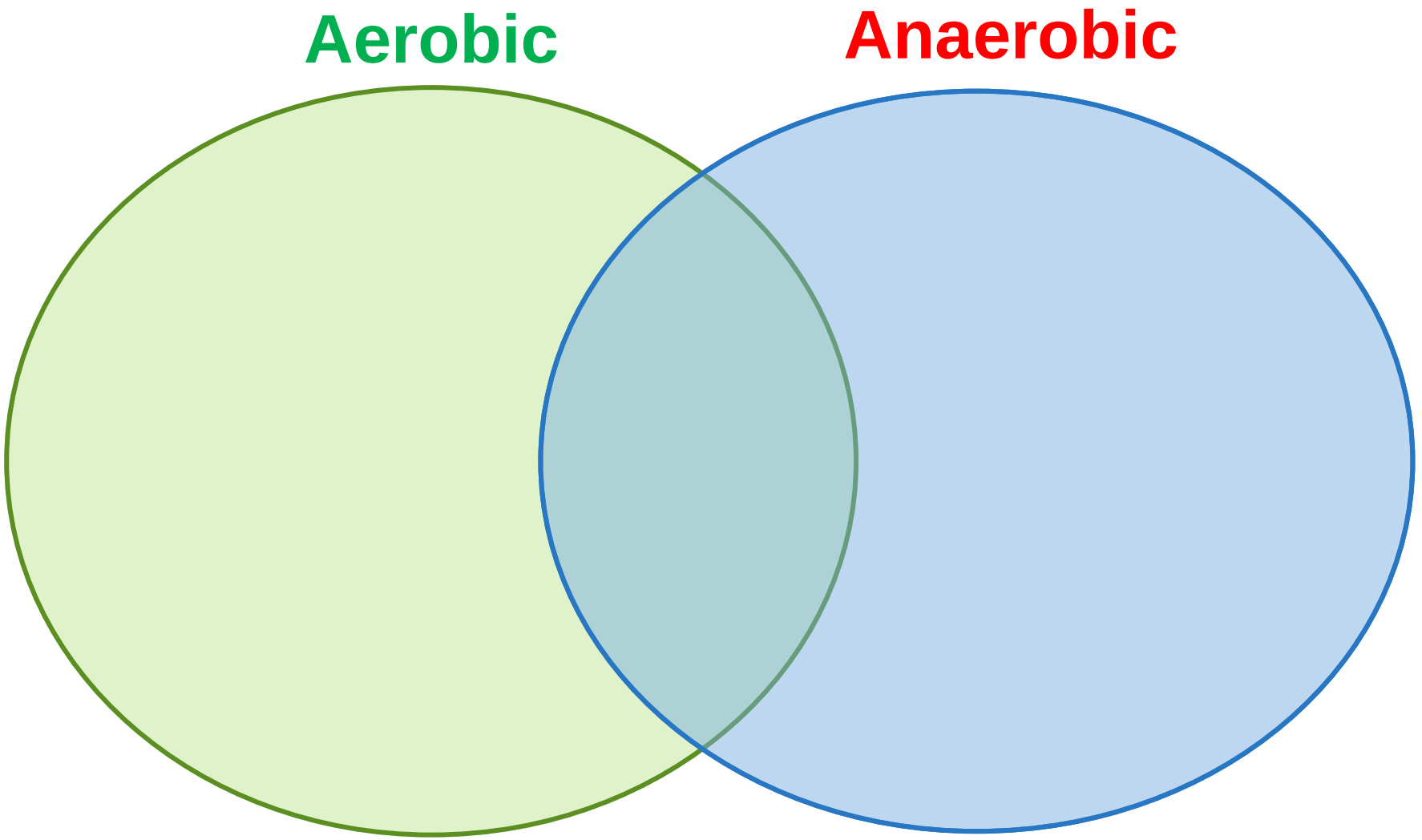
Fermentation: 0 ATP

(lactic acid or alcohol)

Total = 2 ATP

Complete the Venn Diagram:
Aerobic vs. Anaerobic Respiration

QUICK CHECK



Complete the Venn Diagram:
Aerobic vs. Anaerobic Respiration

QUICK CHECK