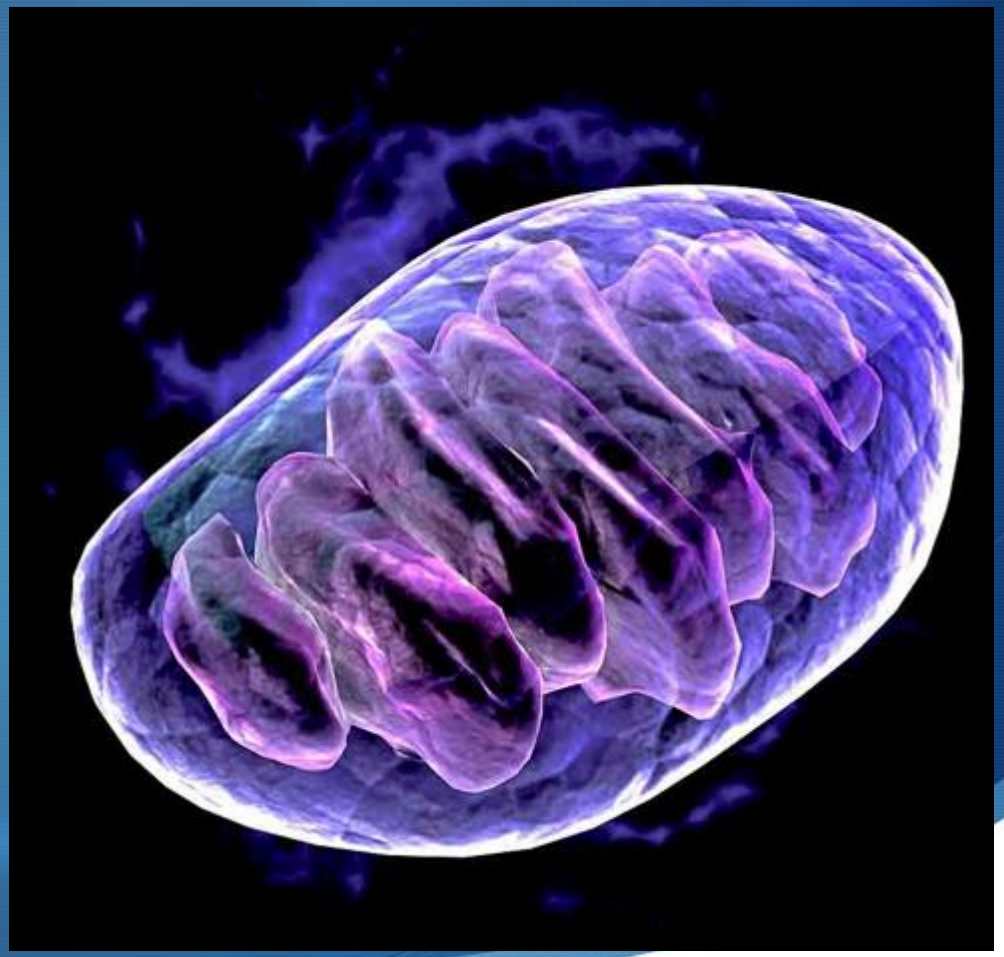
Go to the "Slide Show" shade above

Click on "Play from Beginning"

Chapter 8: Cellular Respiration

Glycolysis



Ellicitation: What do You Think?

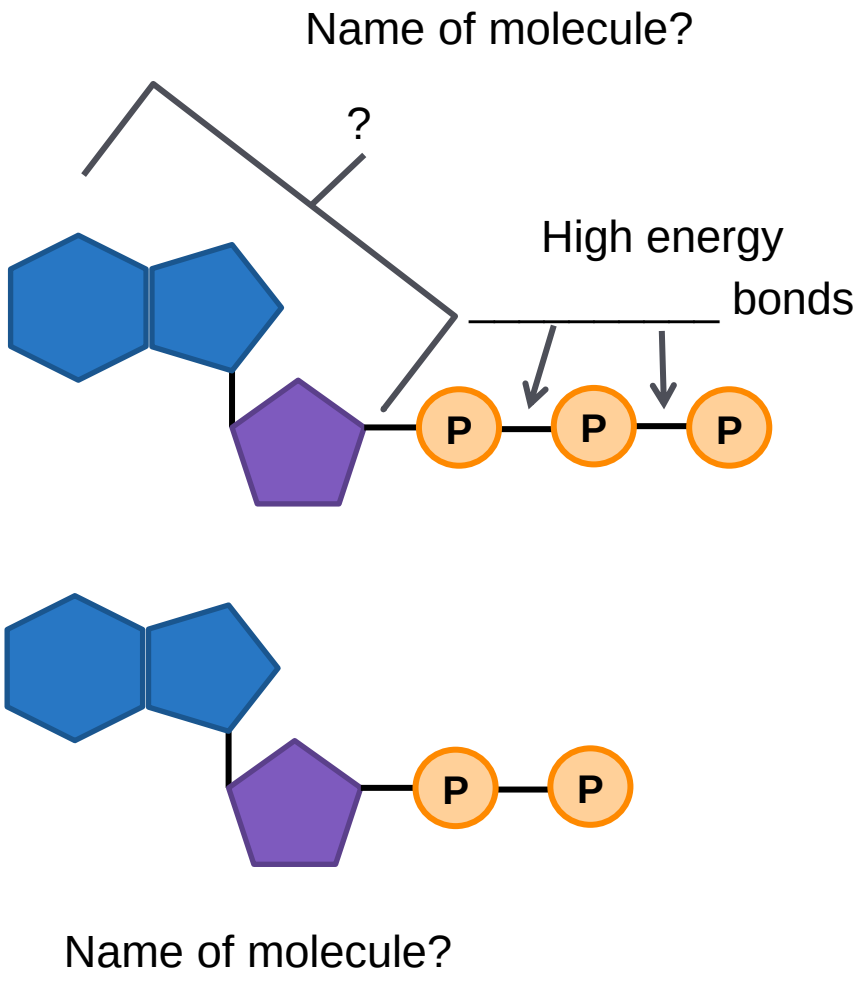
Give a definition or explanation of the following:

- How do organisms obtain energy for life?
- Respiration
- Aerobics
- Why are we exhausted and sore after rigorous exercise?
- Distinguish photosynthesis from cellular respiration.

ATP: Energy for Living Organisms

WARM-UP

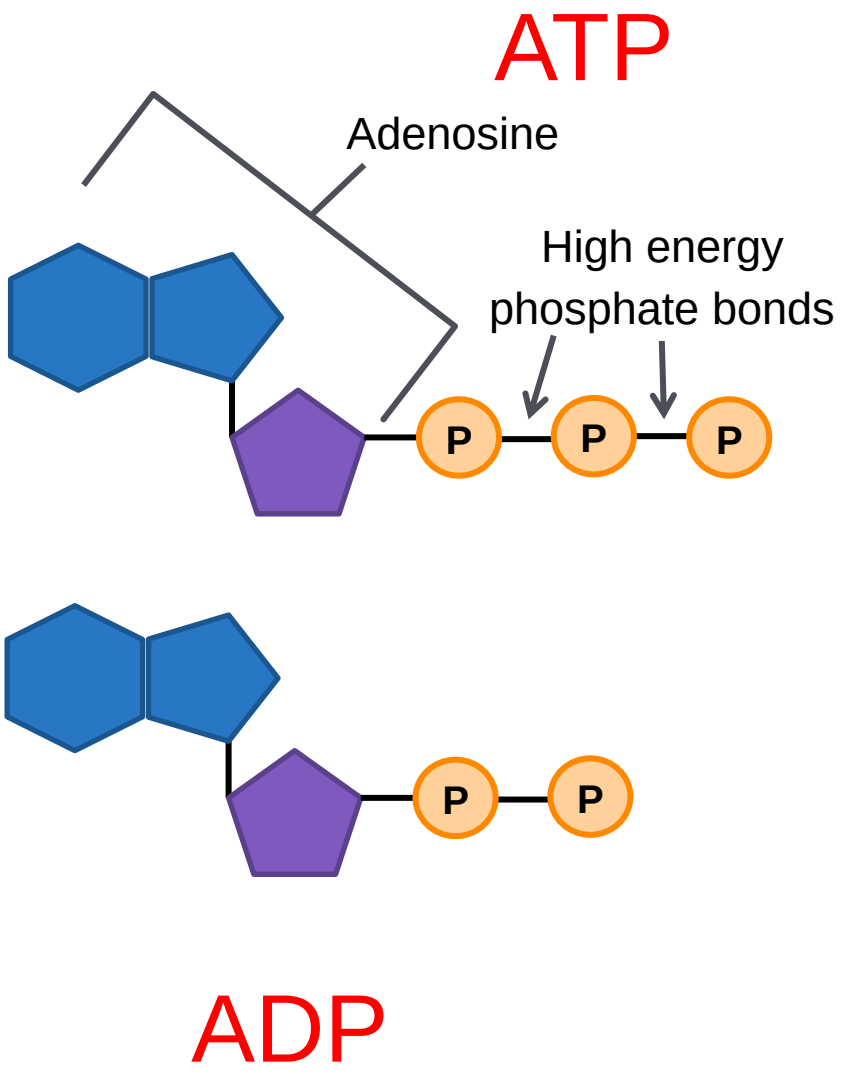
- _____ _____ **(ATP)** is an energy source for all living organisms.
- ATP is composed of one adenosine molecule and _____ phosphates.
- **Adenosine** _____ **(ADP)** is a compound composed of one adenosine and ____ phosphate groups.
- _____ is converted to _____ producing energy when a phosphate is removed.



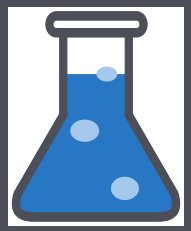
ATP: Energy for Living Organisms

WARM-UP

- **Adenosine triphosphate (ATP)** is an energy source for all living organisms.
- ATP is composed of one adenosine molecule and three phosphates.
- **Adenosine diphosphate (ADP)** is a compound composed of one adenosine and two phosphate groups.
- ATP is converted to ADP and produces energy when a phosphate is removed.



Lesson Objectives

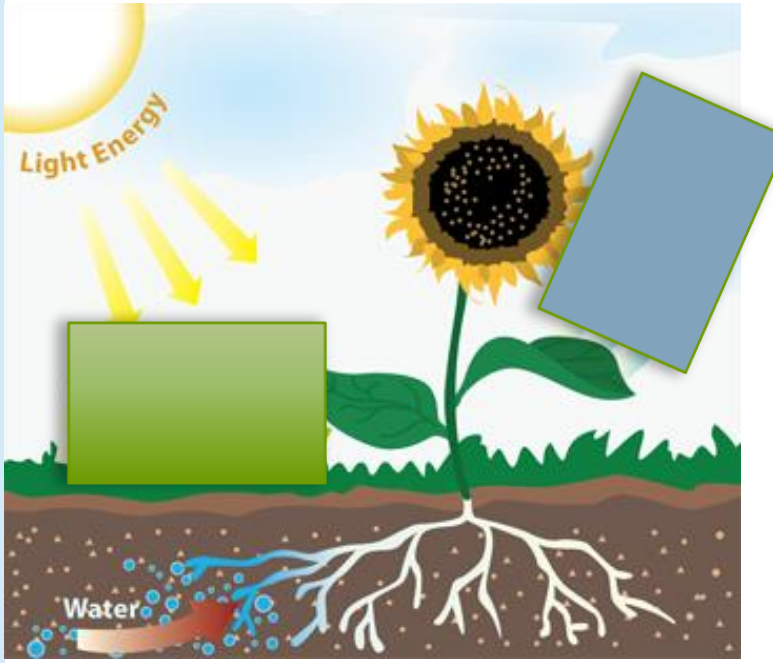


By the end of this lesson, you should be able to:

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

Photosynthesis and Cellular Respiration provide Energy for Life

- **LIFE** requires **ENERGY.**
- In almost all ecosystems, energy ultimately comes from the **SUN**.
- In **Photosynthesis**,
  - some of the energy in sunlight is captured by chloroplasts.
  - atoms of carbon dioxide and water are rearranged.
  - sugar and oxygen are produced.



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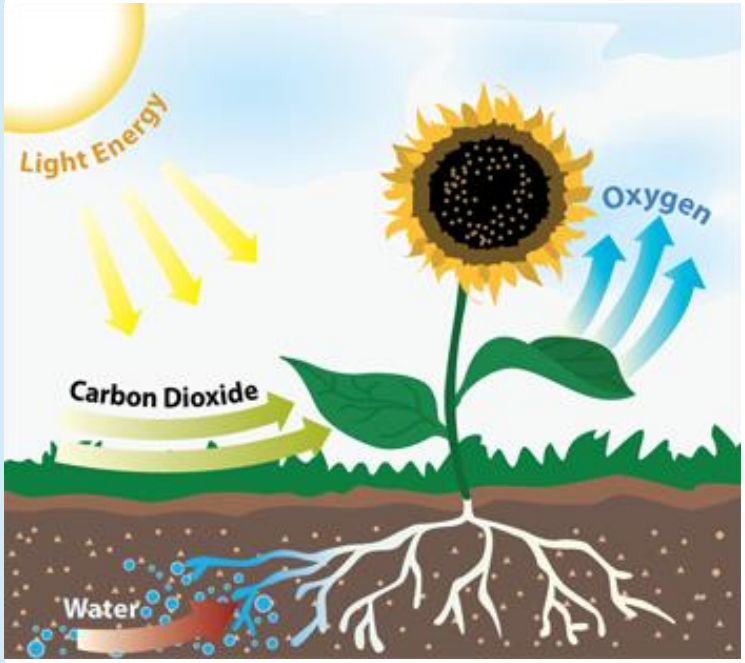
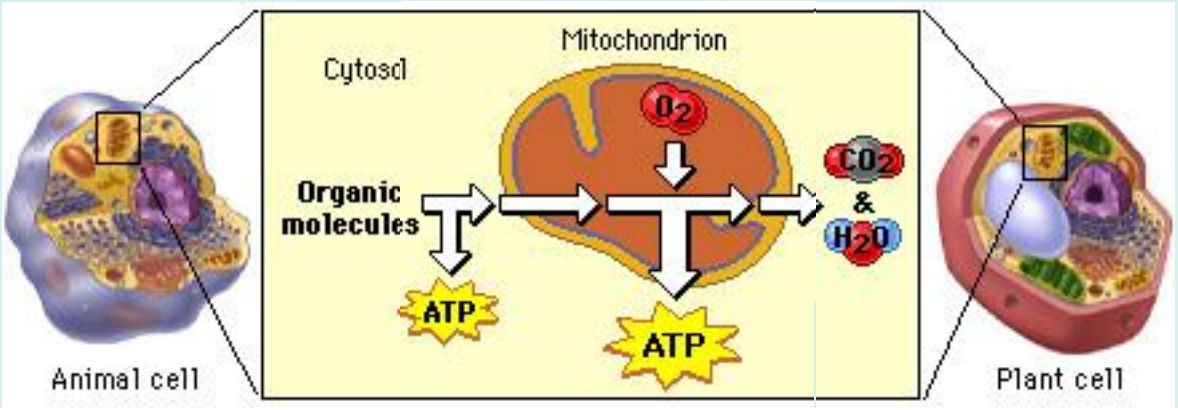
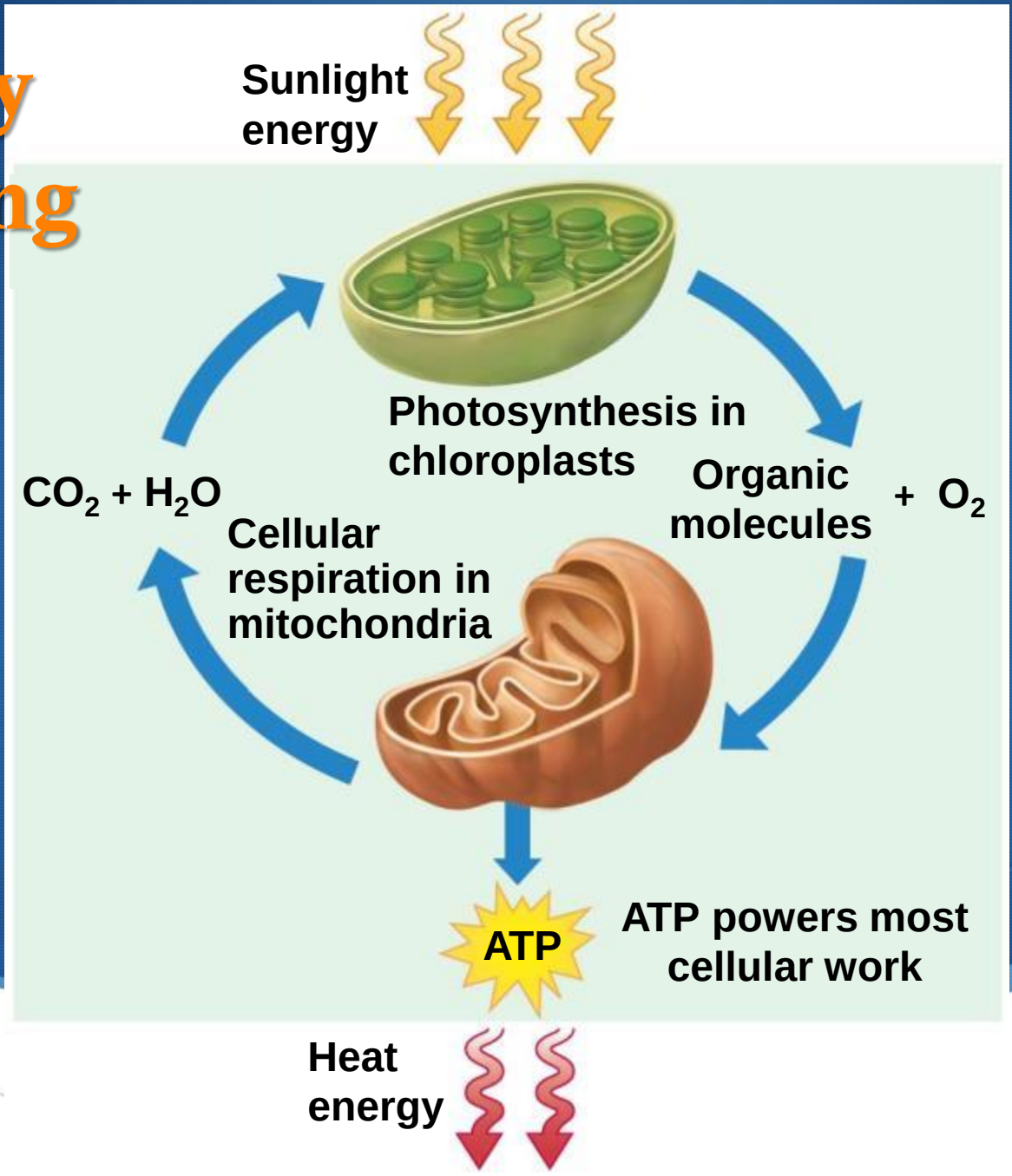


Photosynthesis and Cellular Respiration provide Energy for Life

- **Cellular Respiration** takes place in the **mitochondria** of **eukaryotic** cells.
- In **Cellular Respiration**,
  - **sugar** is broken down to **carbon dioxide** and **water;**
  - the cell captures some of the released energy to make **ATP.**
- In these **energy conversions**, some energy is lost as **heat**.



Energy Coupling



Photosynthesis and Cellular Respiration

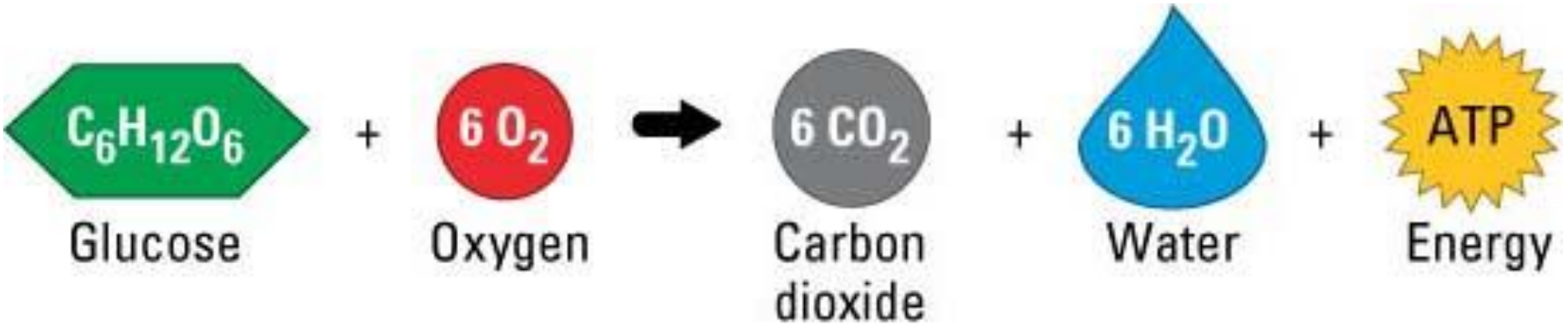
Photosynthesis is carried out by plants, algae, and some bacteria.

Cellular respiration is carried out by **ALL** living organisms.

Plants undergo photosynthesis and cellular respiration. Animals (e.g. tiger, insects) are only capable of cellular respiration.

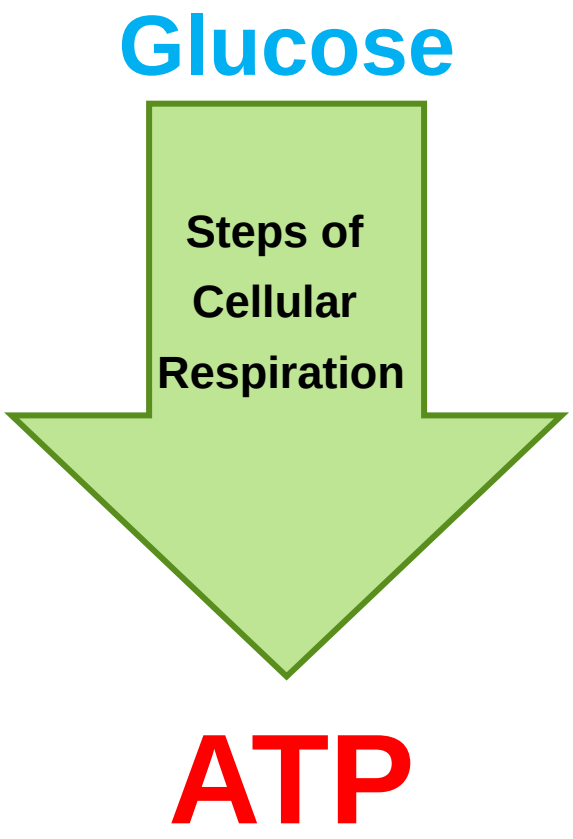
Cellular Respiration

Cellular Respiration is an **exergonic** (energy-releasing) process that **transfers energy** from the bonds in **Glucose** to form **ATP.**



Energy for Living Organisms

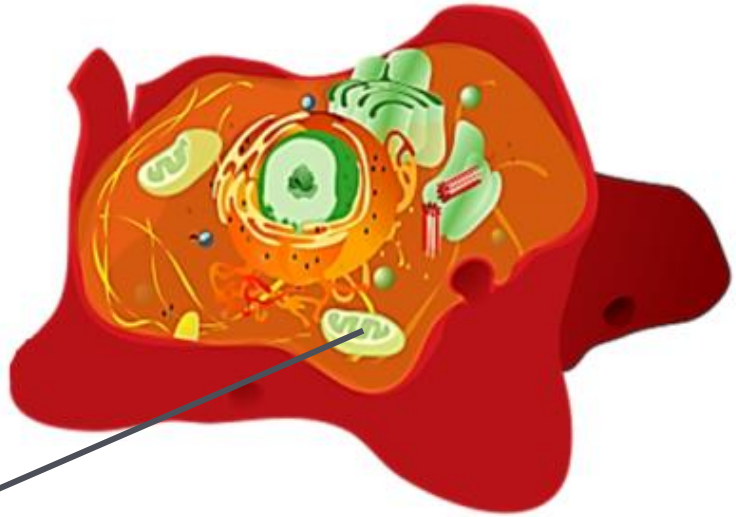
Cellular respiration is a process that breaks down glucose to provide energy in the form of ATP for metabolic processes.



What is the Site of Cellular Respiration?

? Cell

? Cell

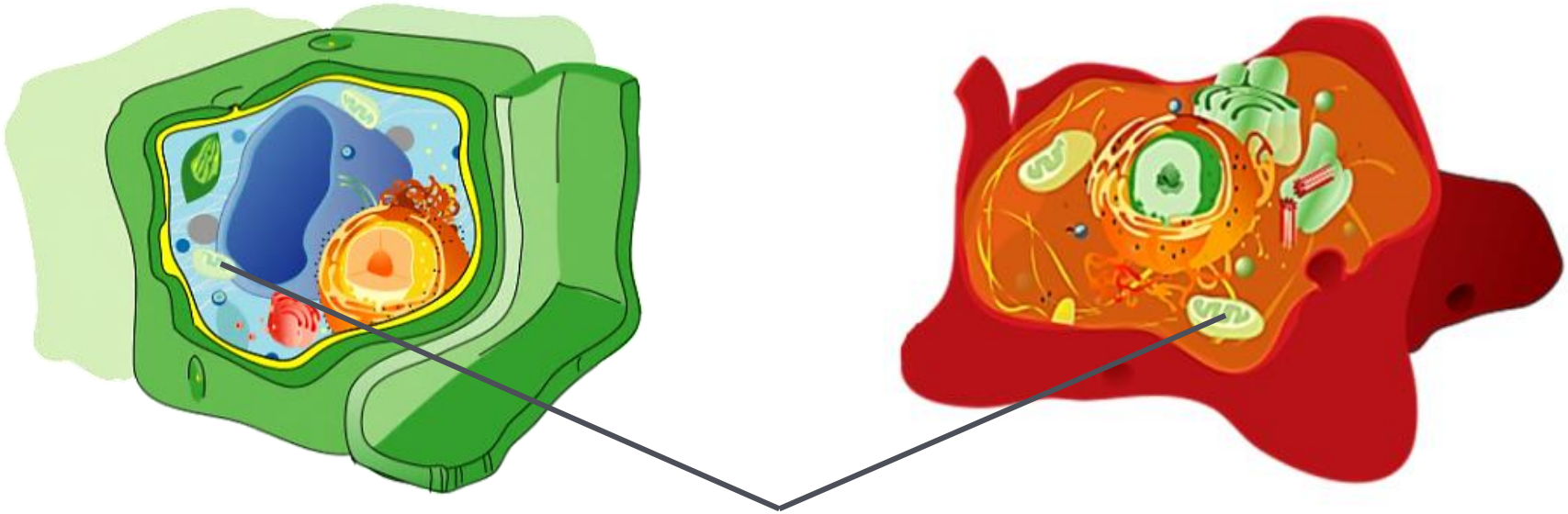


?

What is the Site of Cellular Respiration?

Plant Cell

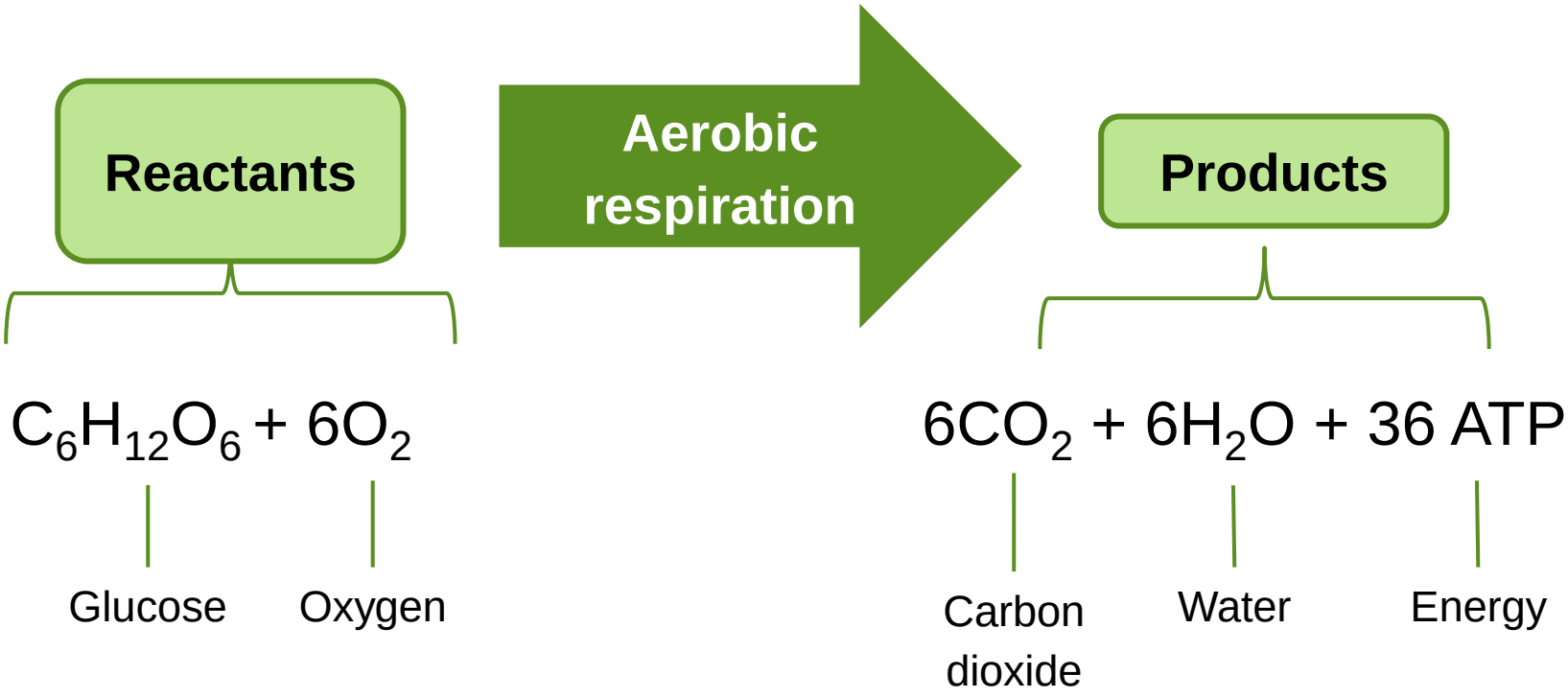
Animal Cell



Mitochondria

Aerobic Cellular Respiration: Oxygen Present

How do cells **extract energy** from **glucose**?



Cells capture Energy from Electrons "falling" from Organic Fuels to Oxygen

$C_6H_{12}O_6 + 6O_2$

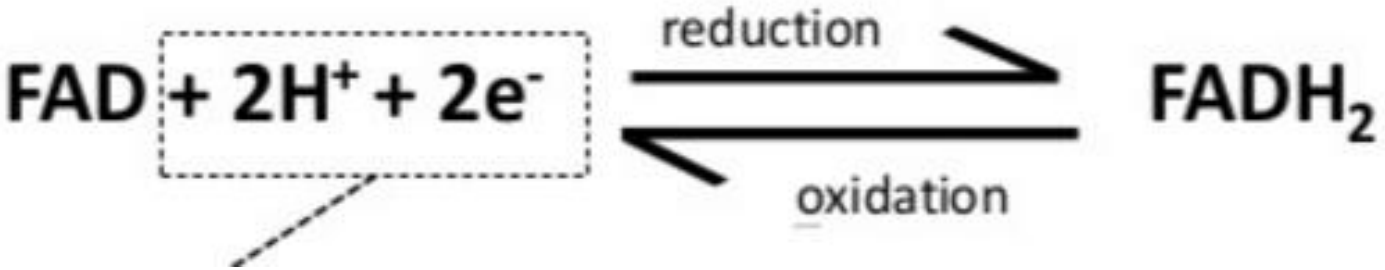
- Cells **extract energy** from **glucose** by the **transfer of electrons** during chemical reactions.
- During **Cellular Respiration**,
  - **Electrons** are transferred from **glucose** to **oxygen**
  - **Energy** is released (exergonic reaction).
- **Oxygen** strongly attracts **electrons**.
- An **electron** **loses potential energy** when it is transferred to oxygen.

Cells capture Energy from Electrons "falling" from Organic Fuels to Oxygen

- **Cellular Respiration** is a **controlled** descent of **electrons** … like rolling **down an energy hill**.
- **Energy** is **released in small amounts** and can be stored in the **chemical bonds** of **ATP**.
- The movement of **electrons** from one molecule to another is an **Oxidation-Reduction reaction**, or **Redox reaction**.

Cells capture Energy from Electrons "falling" from Organic Fuels to Oxygen

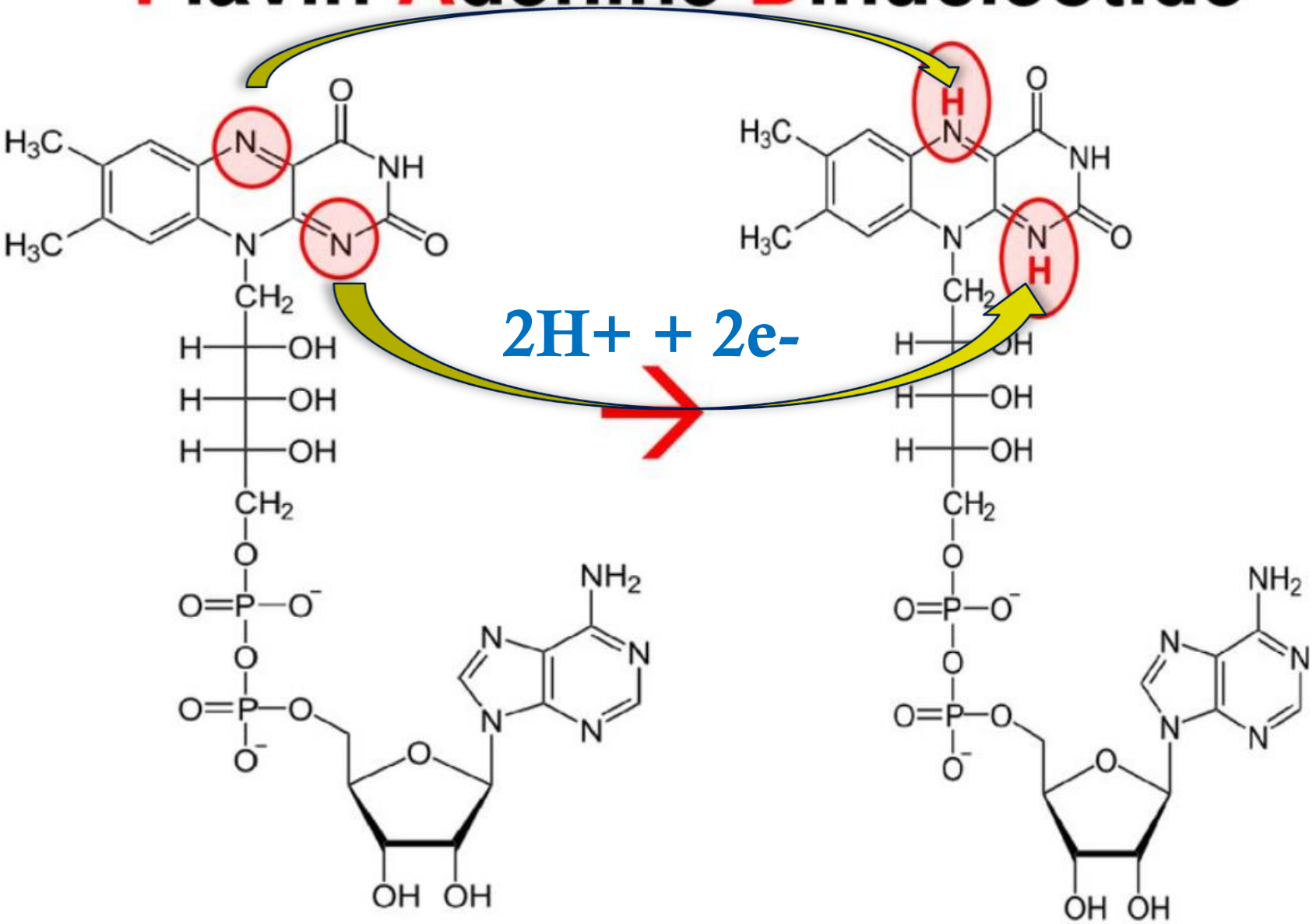
- A lot of energy is stored **in the bonds** between the carbon and hydrogen atoms in glucose.
- During cellular respiration, **redox reactions** basically transfer this bond energy in the form of **electrons** from glucose to molecules called electron carriers.



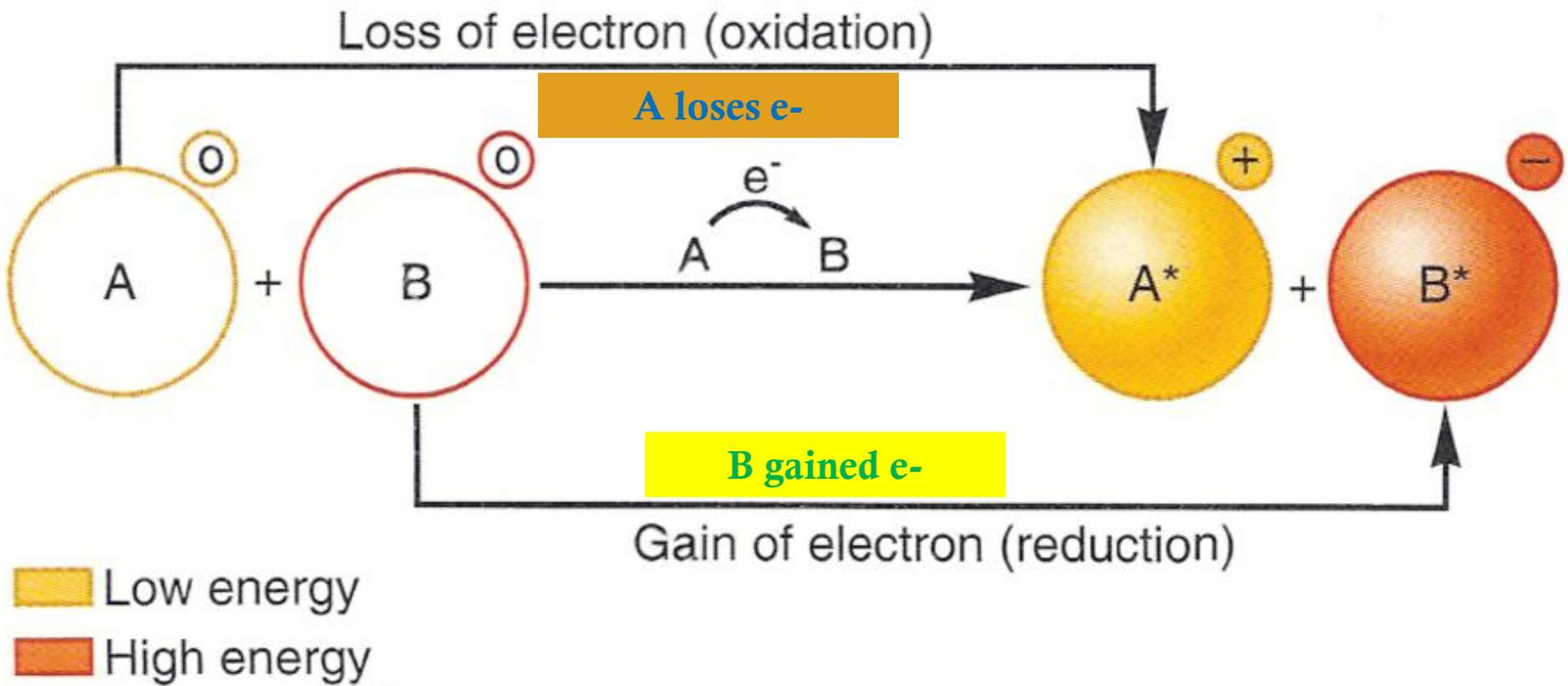
- So an **electron carrier** is basically a molecule that transports electrons during cellular respiration.

FAD→FADH2

Flavin Adenine Dinucleotide

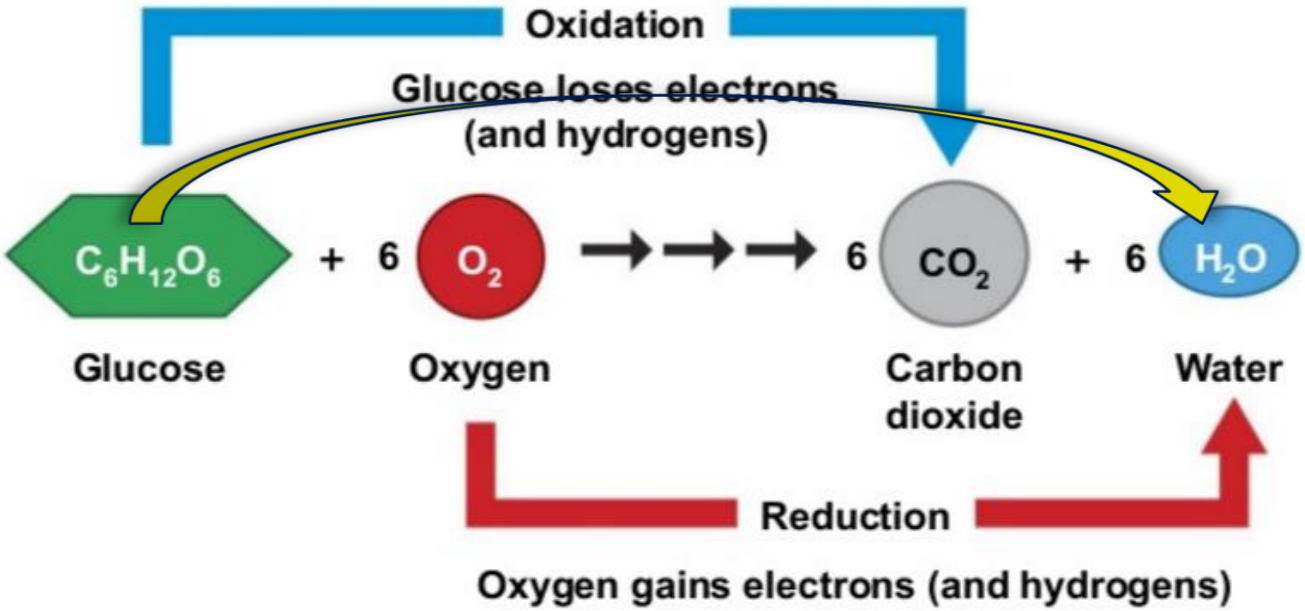


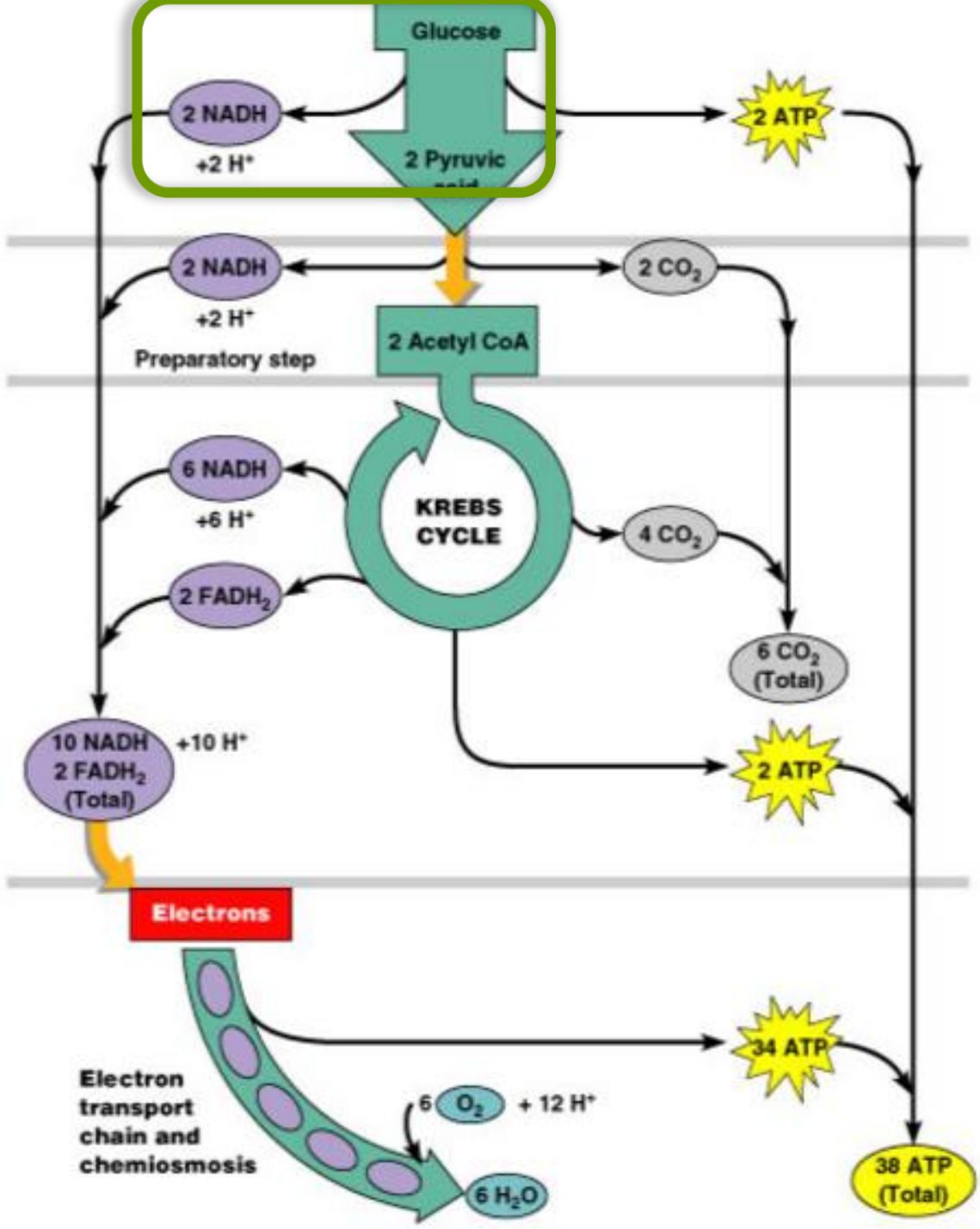
- In a **Redox reaction**,
  - The **loss of electrons** from one substance is called **Oxidation**.
  - The **addition of electrons** to another substance is called **Reduction.**
  - A molecule is **oxidized** when it **loses** **one or more electrons.**
  - A molecule is **reduced** when it **gains** **one or more electrons**.



Cells capture Energy from Electrons "falling" from Organic Fuels to Oxygen

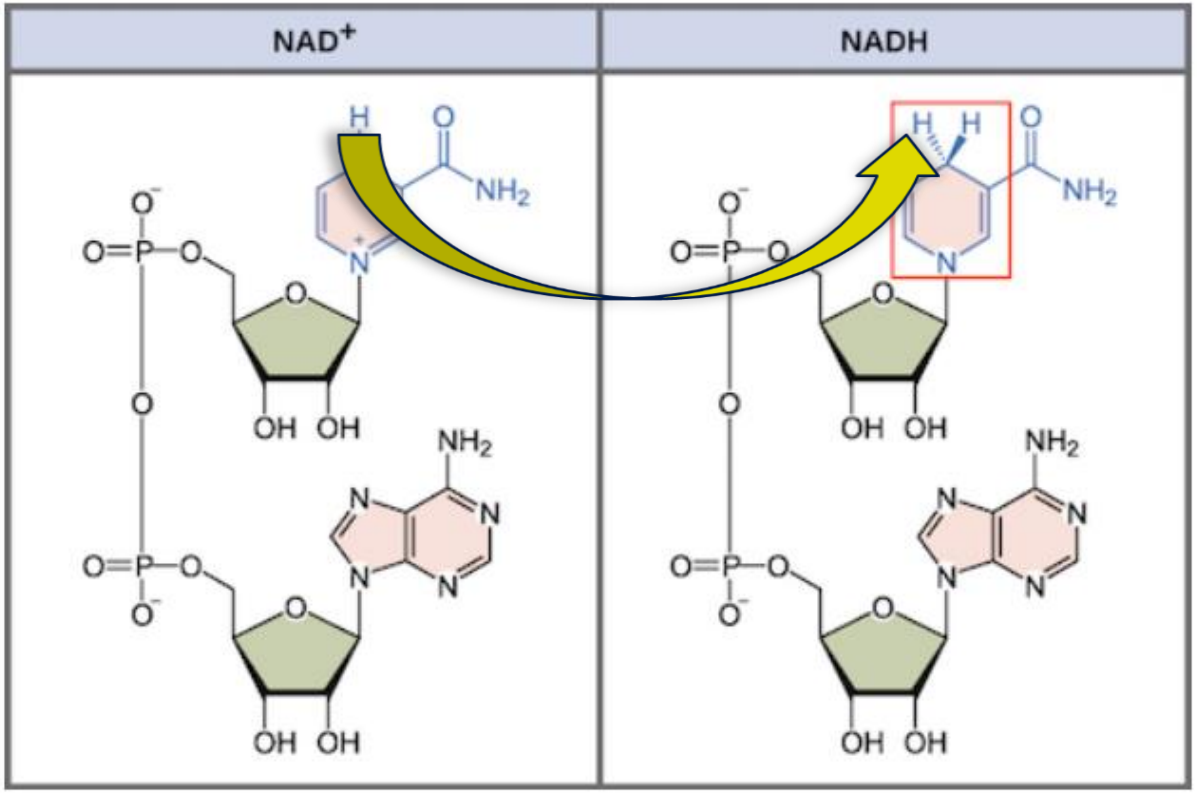
- The **Cellular Respiration** equation is helpful to show the changes in **Hydrogen** atoms (with their **electrons**).
  - **Glucose loses** its hydrogen atoms & some **electrons**, becoming **oxidized** to CO_2.
  - **Oxygen gains electrons** & **Hydrogen** atoms being **reduced** to H_2O.





- **Glucose** is **oxidized**
- **NAD+**
  - accepts electrons
  - & is **reduced** to **NADH.**

NAD+ → NADPH



Glucose is **oxidized**

NAD+

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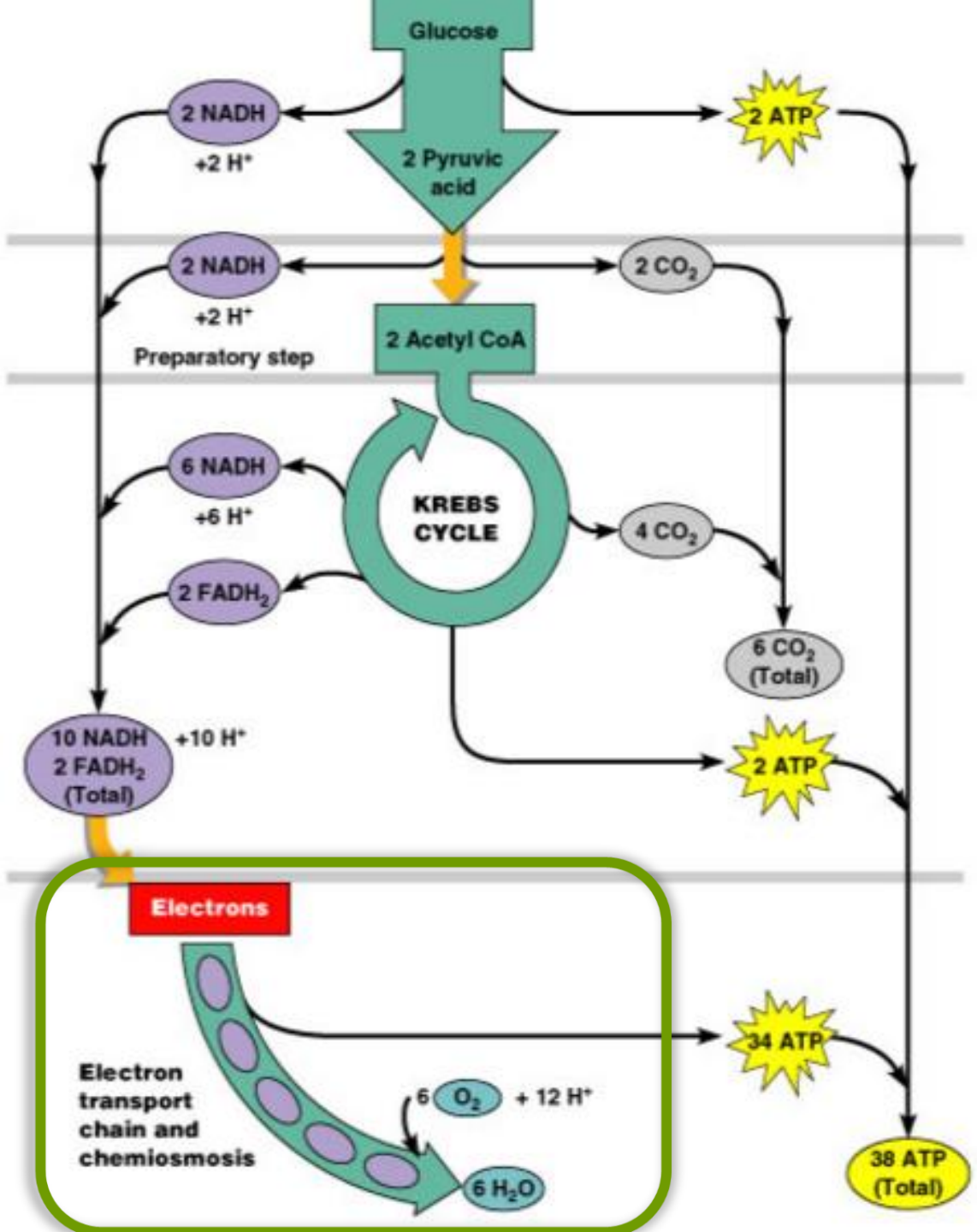

- **NADH** delivers electrons to a string of electron carrier molecules, which moves electrons **down an energy hill**.
- These carrier molecules constitute an **Electron Transport Chain**

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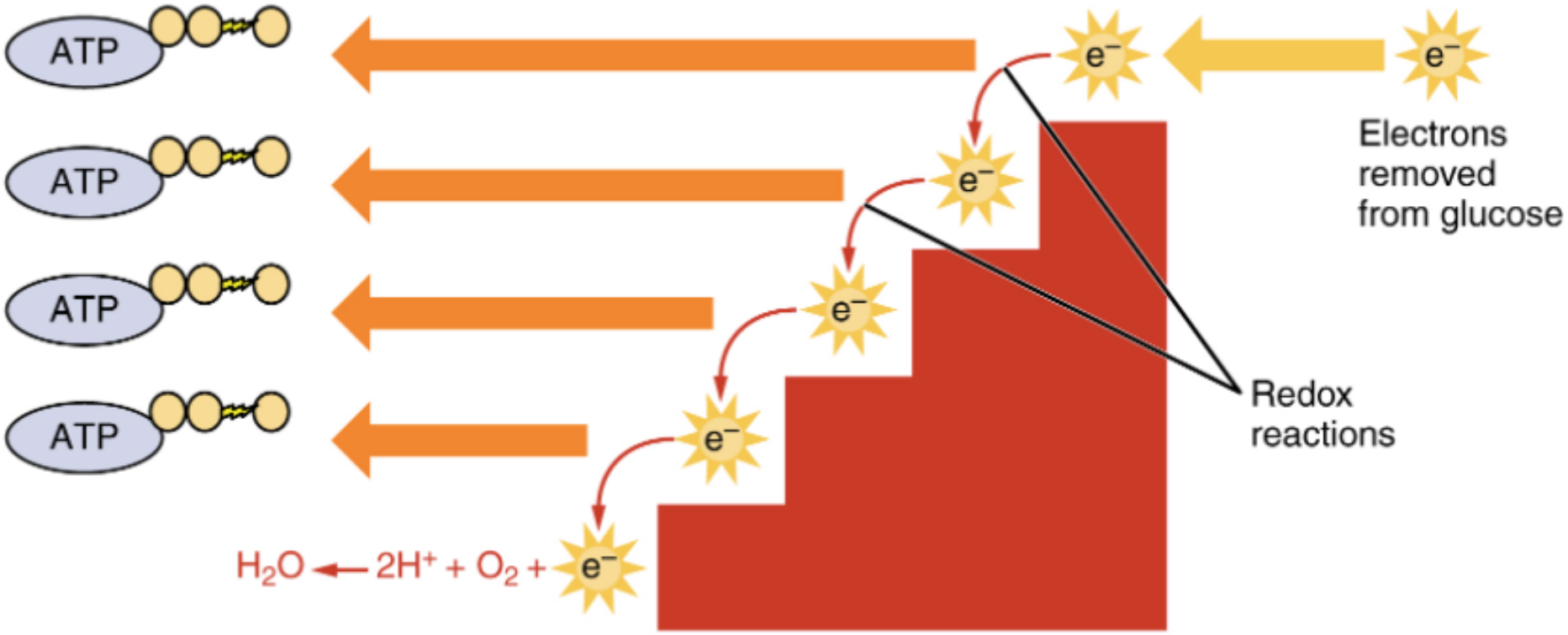
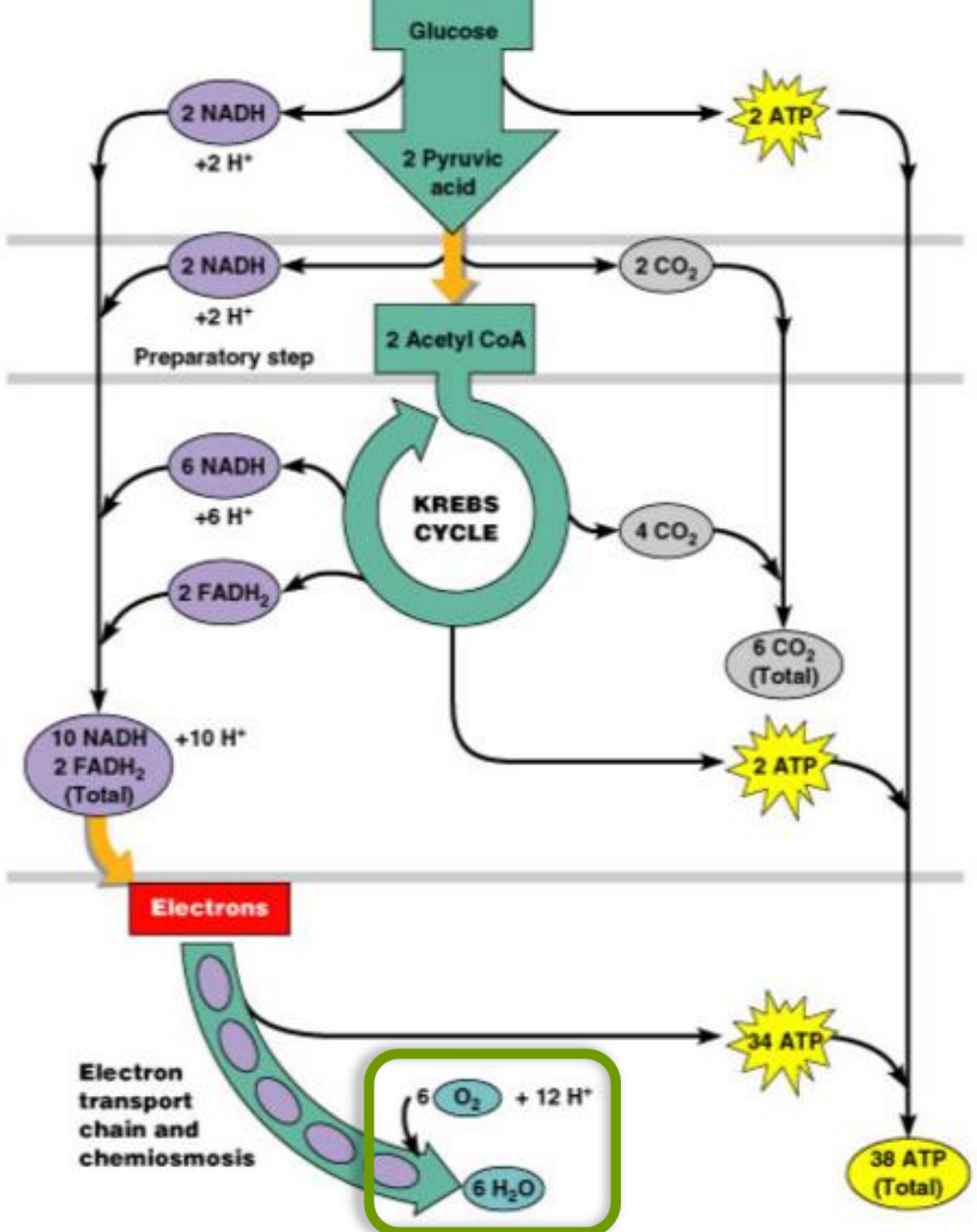
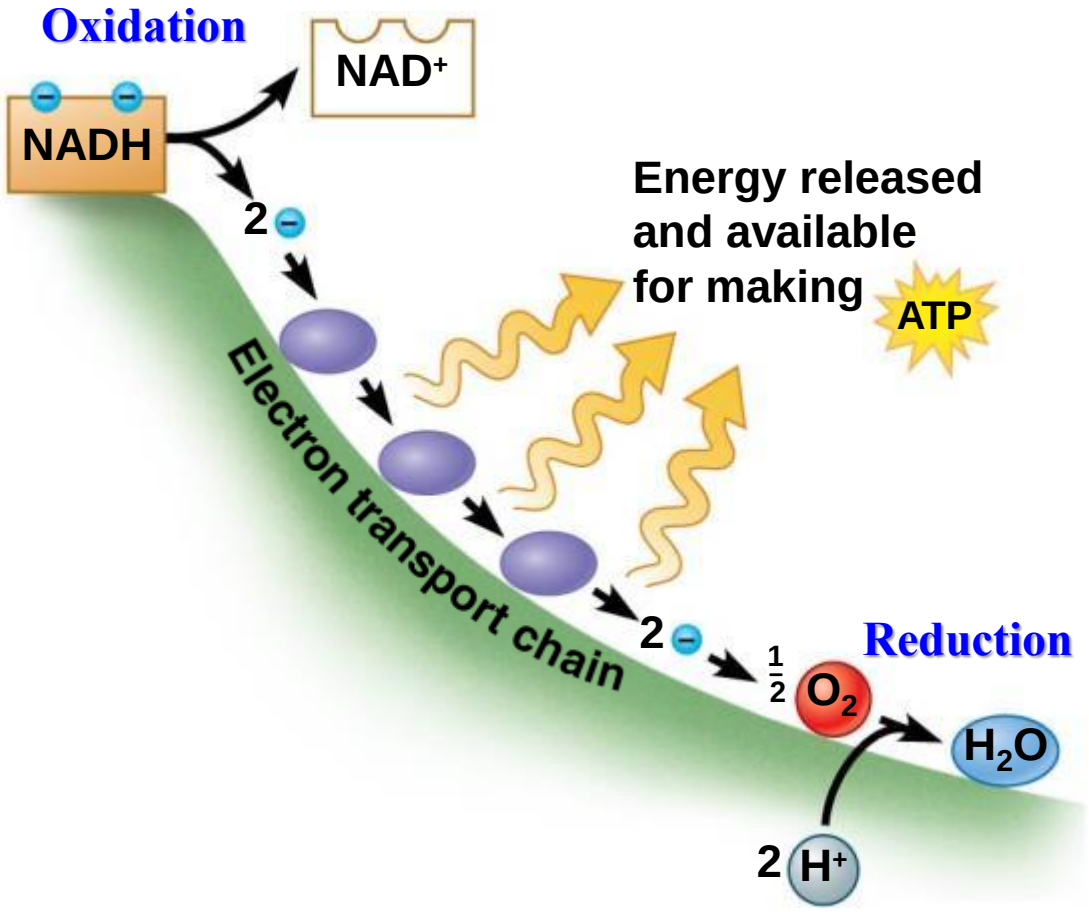


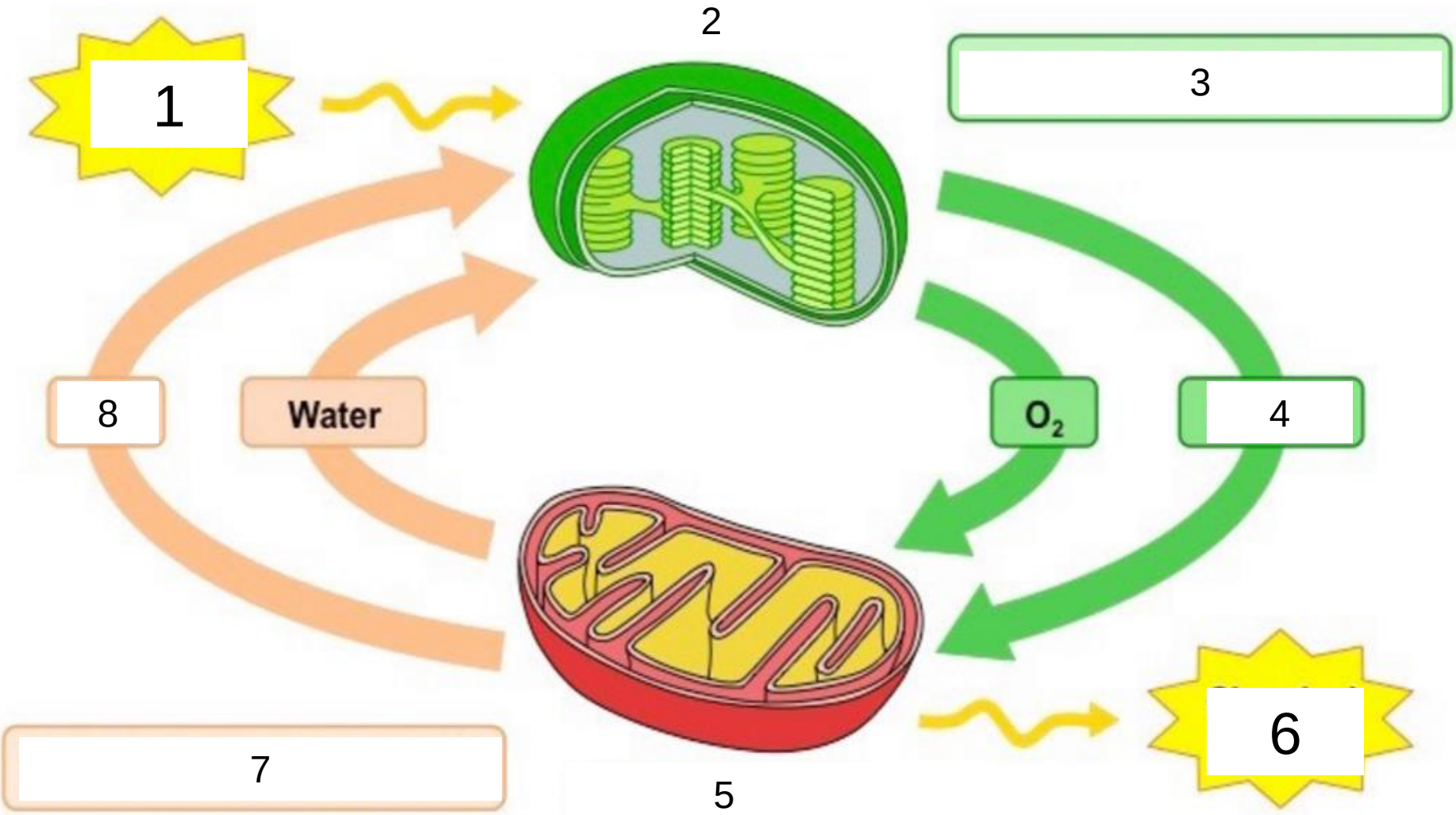


- At the bottom of the hill is **Oxygen**, which
  - accepts two electrons
  - picks up two H^+
  - becomes **reduced** to **Water.**


Oxidation
NAD+
NADH
2
Energy released
and available
for making
ATP
Electron transport chain
2
Reduction
1/2 O2
H2O
2 H+

QUICK CHECK

Use the following terms to label the diagram:
CO_2, cellular respiration, chemical energy, chloroplast, glucose, light energy, mitochondria, photosynthesis



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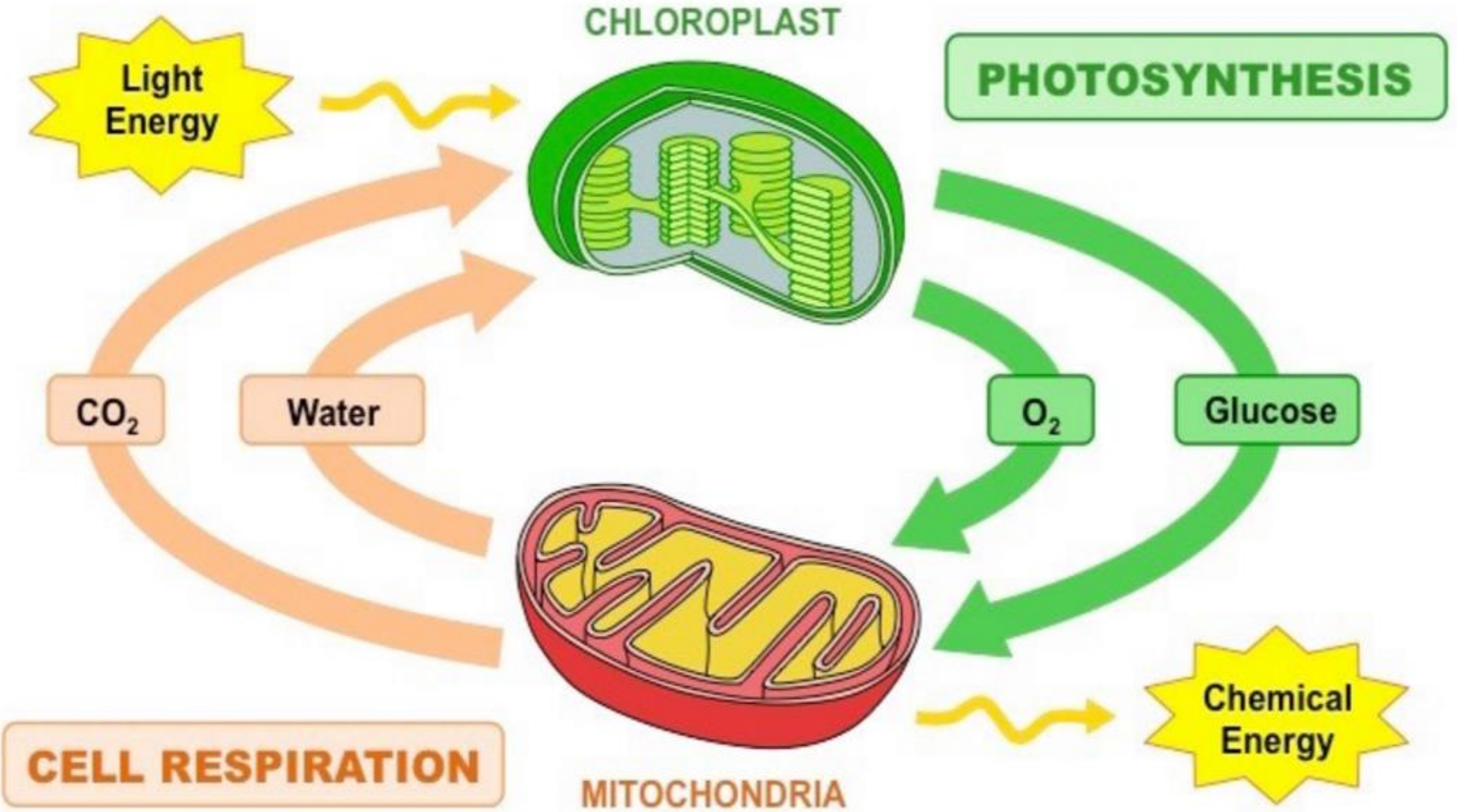
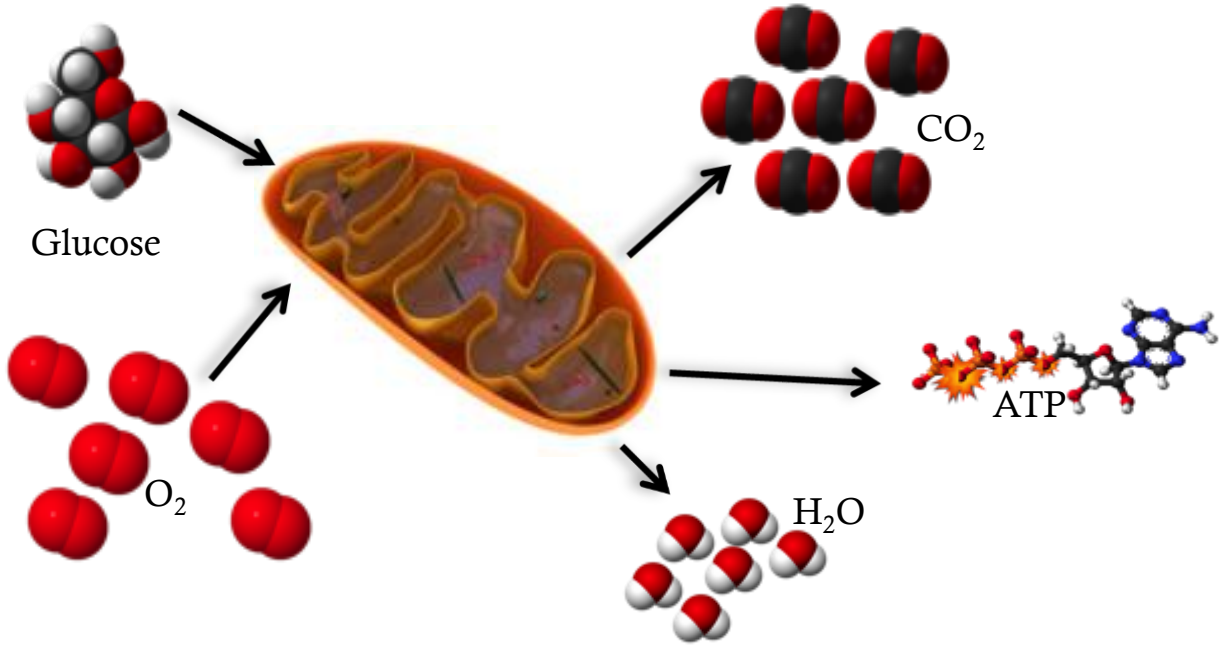


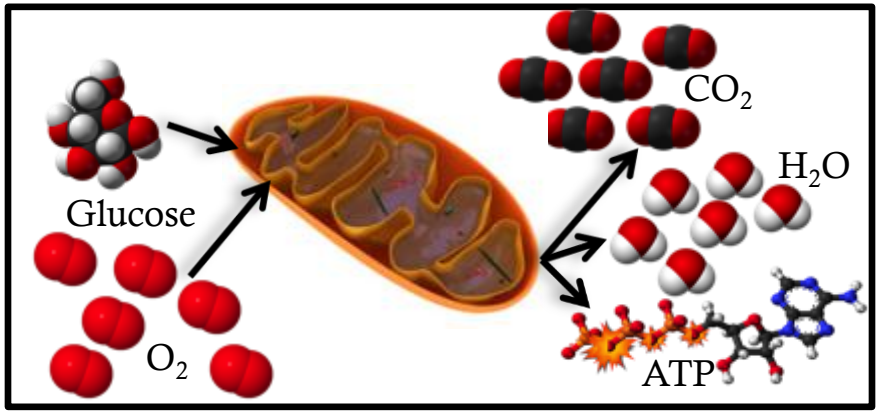
Cell Respiration

- Complex metabolic process by which the chemical bonds in **Glucose** are broken down into **Carbon Dioxide.**
- The **Energy** released is harnessed to make **ATP.**

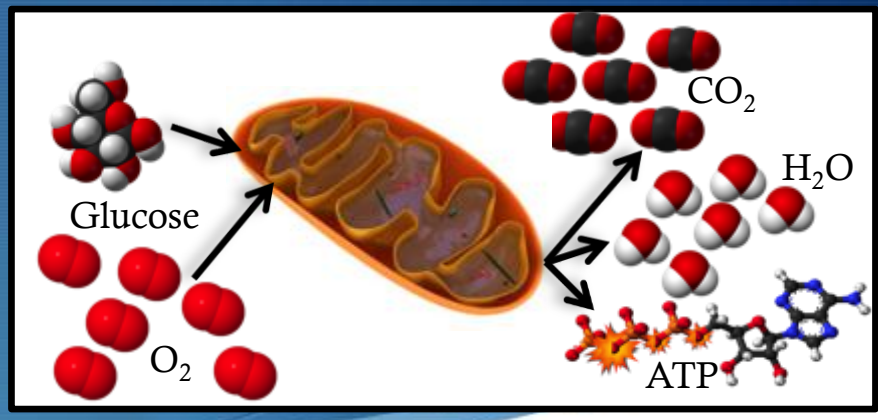


Cell Respiration

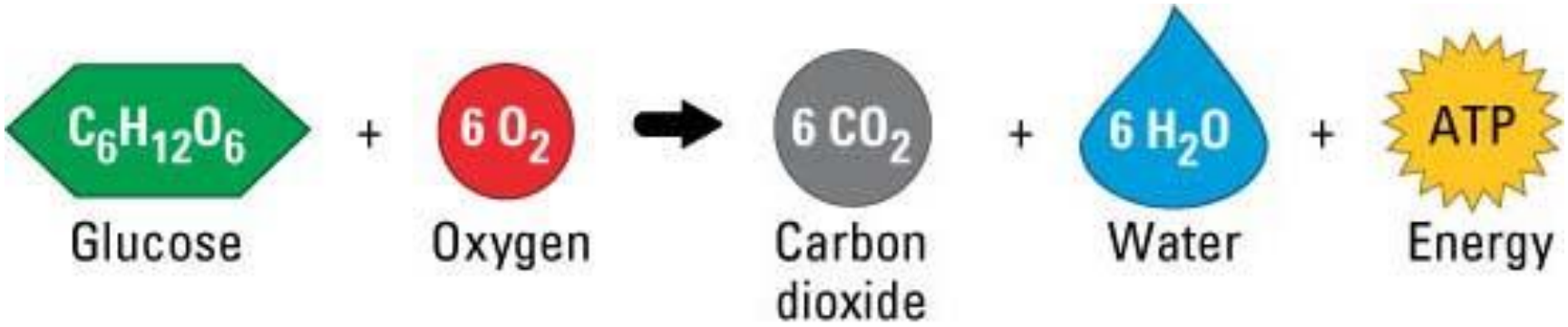
- **ATP** provides cells with the necessary fuel to carry out basic functions.
- Occurs in **ALL CELLS**:
  - **Animal Cells**: Glucose is obtained from food.
  - **Plant Cells**: Glucose is obtained through Photosynthesis.



Cell Respiration



- **Glucose breakdown is a REDOX reaction.**
- **Glucose is oxidized (loses e-) and O_2 is reduced (gains e-).**
- **Breakdown of one Glucose results in 36 ATP.**



Cellular Respiration

- Since **Cellular Respiration** breaks down bonds of **Glucose** to form **Energy**…
  - Is this reaction **Anabolic** or **Catabolic**?
- Since the bonds are broken and water is added…
  - Is this a **Dehydration Synthesis** reaction or a **Hydrolysis** reaction?
- Since **Energy** is **released** in this reaction…
  - Is this reaction **Endergonic** or **Exergonic**?

Cellular Respiration

- Since **Cellular Respiration** breaks down bonds of **Glucose** to form **Energy**…
  - This reaction is **Catabolic**
- Since the bonds are broken and water is added…
  - This reaction is **Hydrolysis**
- Since **Energy** is **released** in this reaction…
  - This reaction is **Exergonic**

What are the Steps of Cellular Respiration?

Three Major Stages:

1. **Glycolysis (splitting of sugar):** Cytoplasm

   Transition Reaction

   Migration from Cytoplasm to Mitochondrial Matrix.

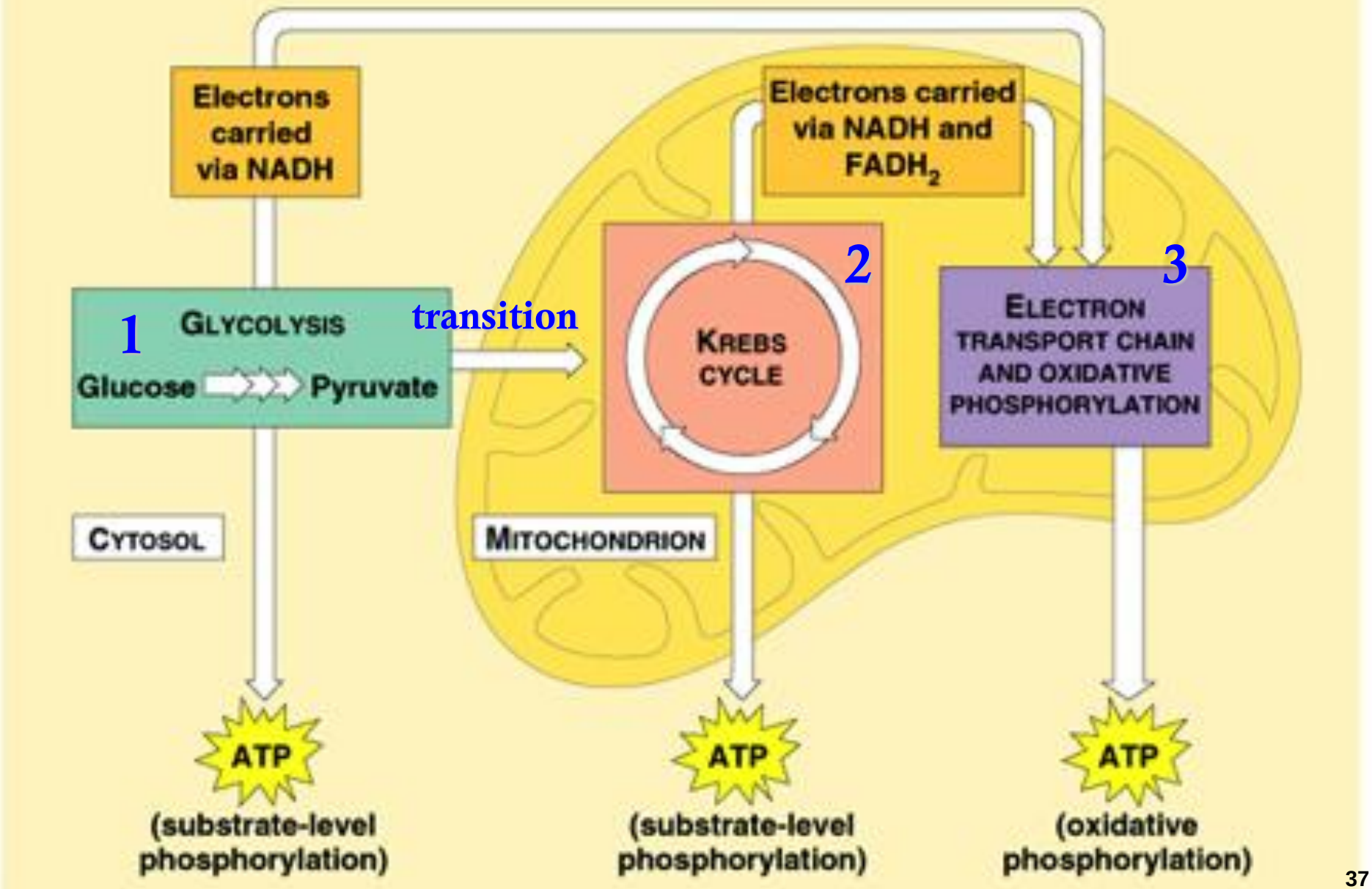
2. **Krebs Cycle (Citric Acid Cycle)**

   Mitochondrial Matrix

3. **Electron Transport Chain (ETC)**

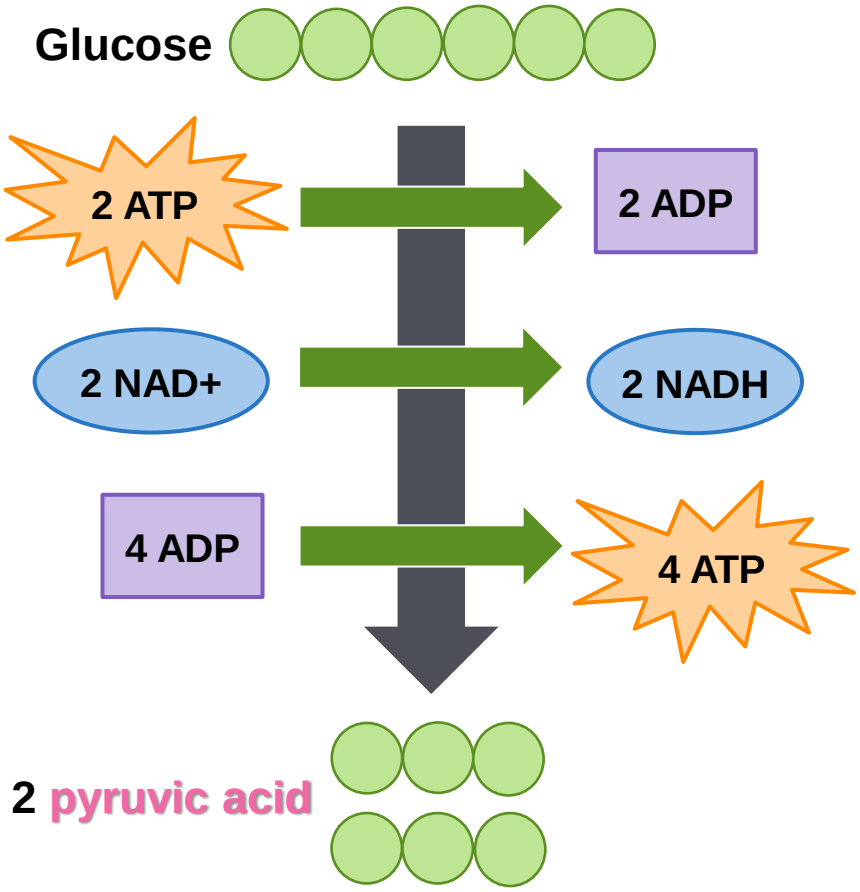
   Inner Mitochondrial Membrane (Cristae)

What are the Steps of Cellular Respiration?

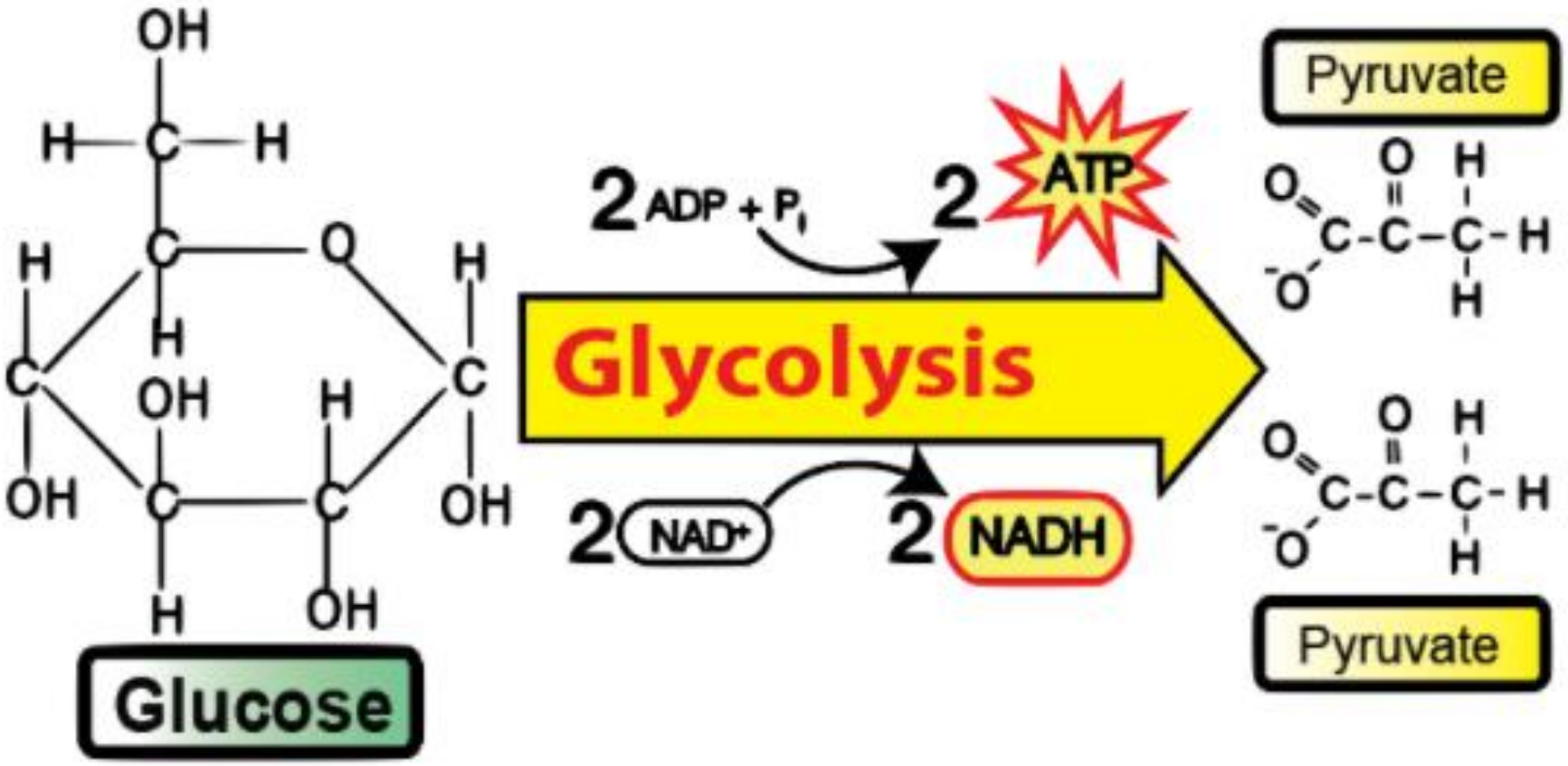


Stage 1: Glycolysis Overview

- **Glycolysis** is the first stage of the metabolic pathway of cellular respiration that results in the production of ATP.
  - **TWO ATP** are used to start the process.
- Glucose is "SPLIT" & converted into two 3-carbon **pyruvic acid** molecules.
  - Two NAD+ are converted to two NADH.
  - Four ATP are produced with a **net gain of two ATP**.

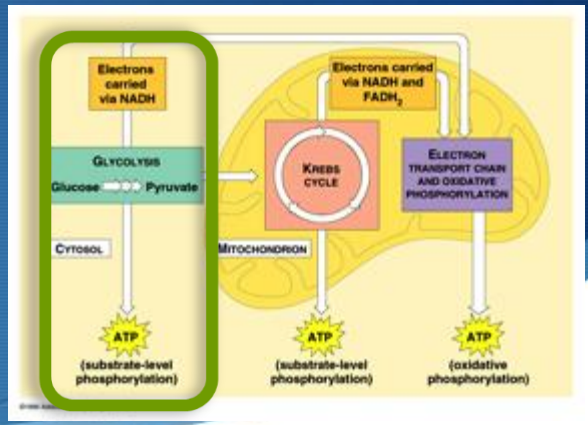


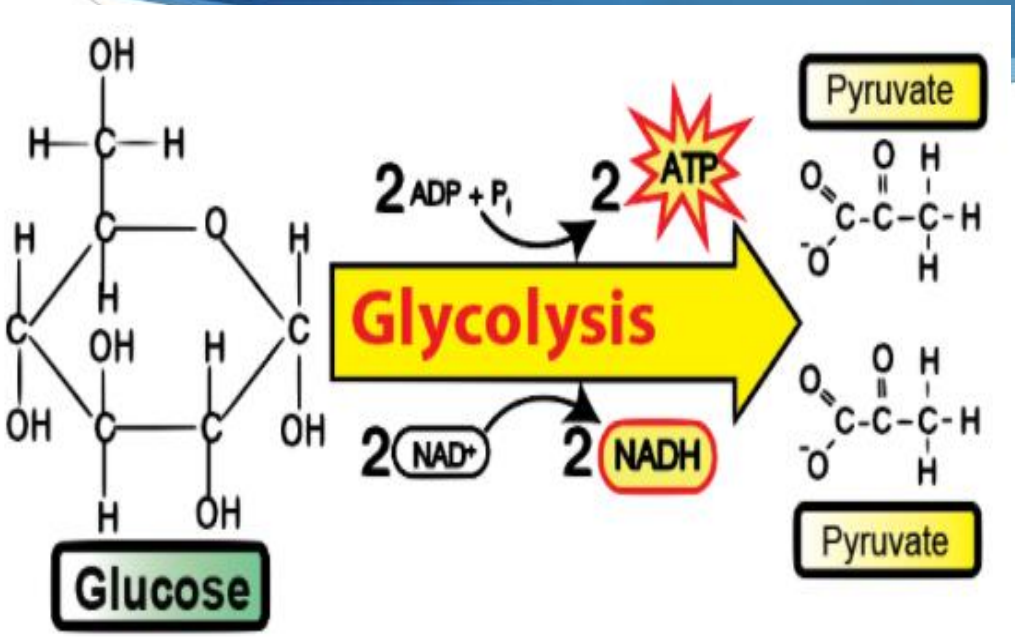
1. Glycolysis ("sugar splitting")



✓**Breaks down glucose** into **two molecules of a three-carbon compound** called **pyruvate.**

1. Glycolysis



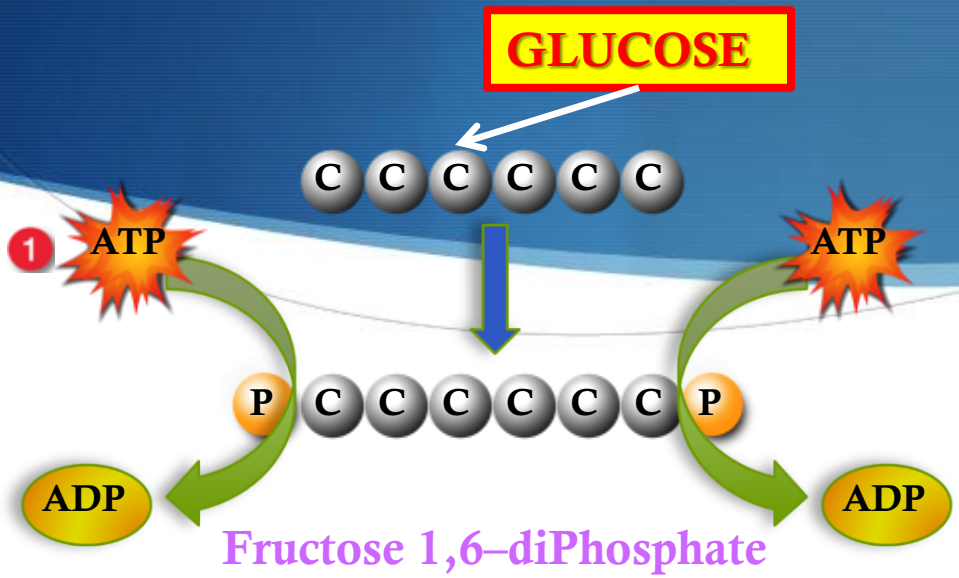


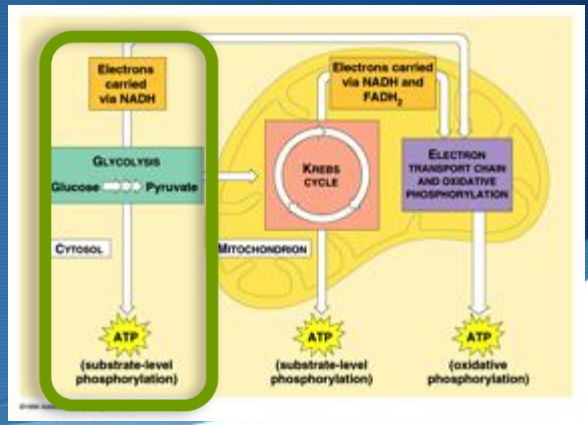
✓Takes place in the cytoplasm of the cell.

- In both eukaryotic and prokaryotic cells.

✓Occurs **anaerobically** (It does not require or use oxygen).

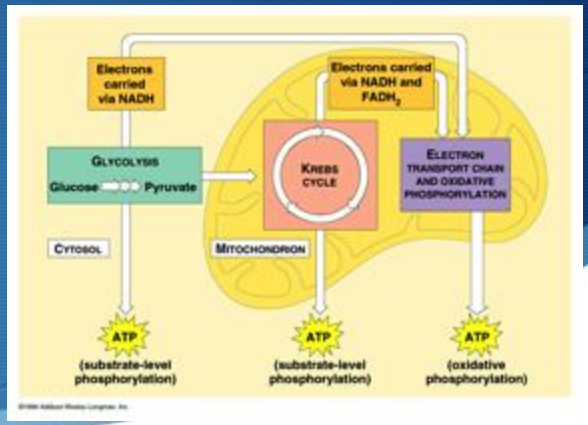
1. Glycolysis

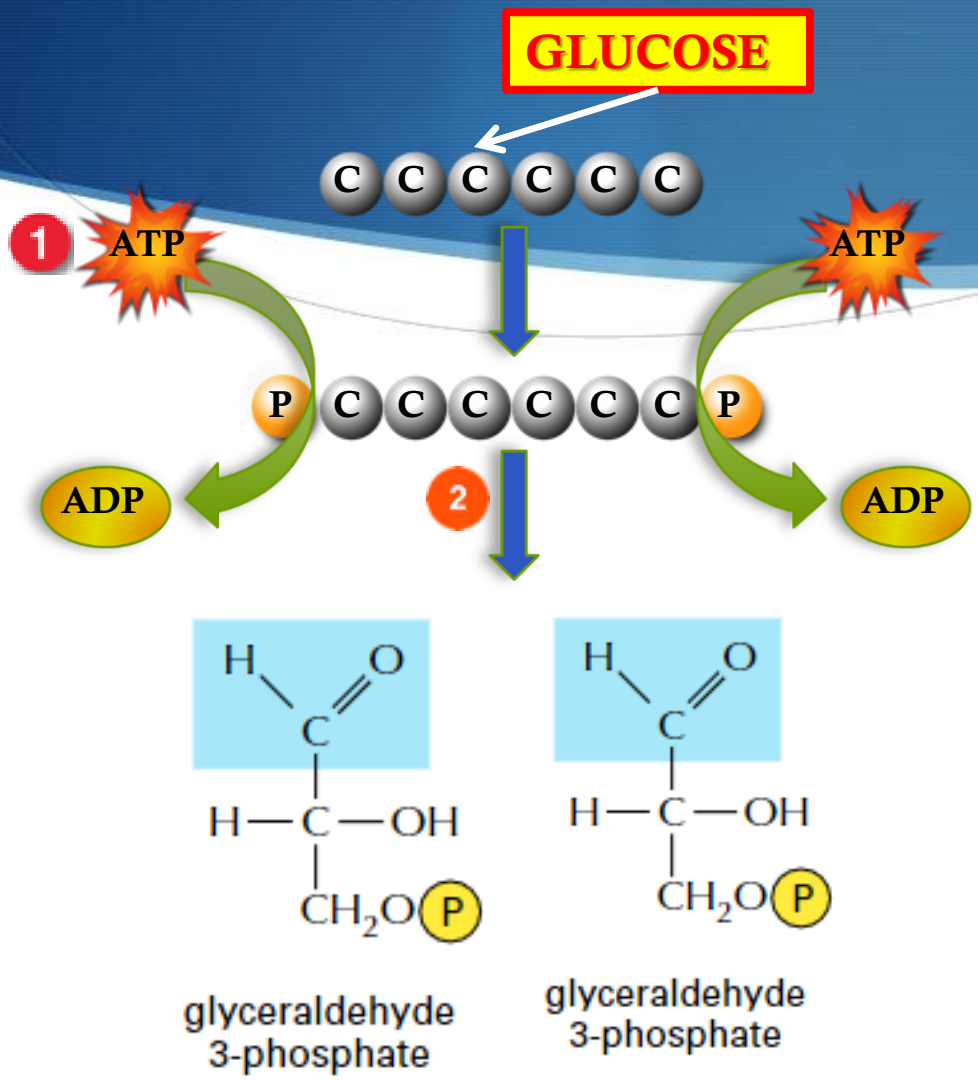




1. Two ATP molecules interact **with glucose** each losing a phosphorus resulting in two ADP molecules.
2. and an unstable sugar phosphate molecule.

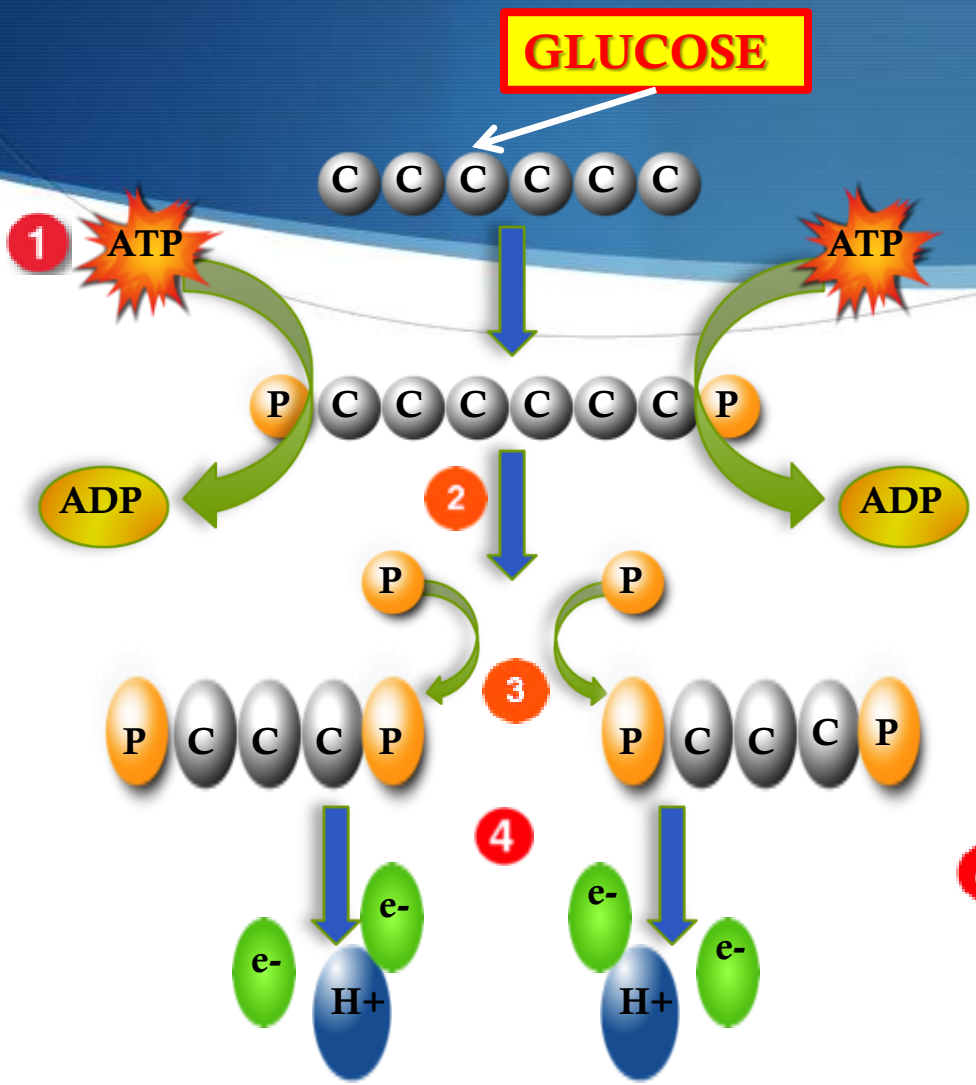
1. Glycolysis

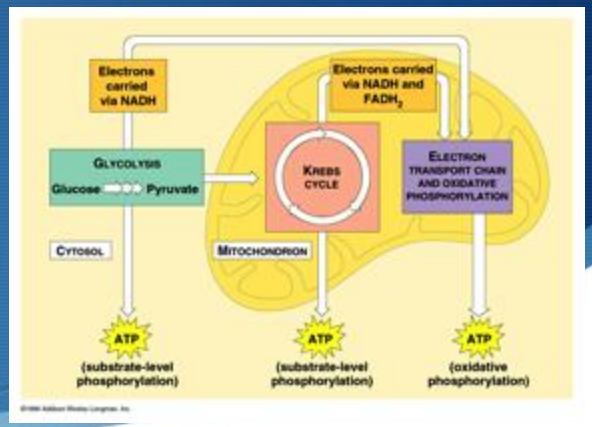




2 **This unstable** molecule breaks into two.

1. Glycolysis

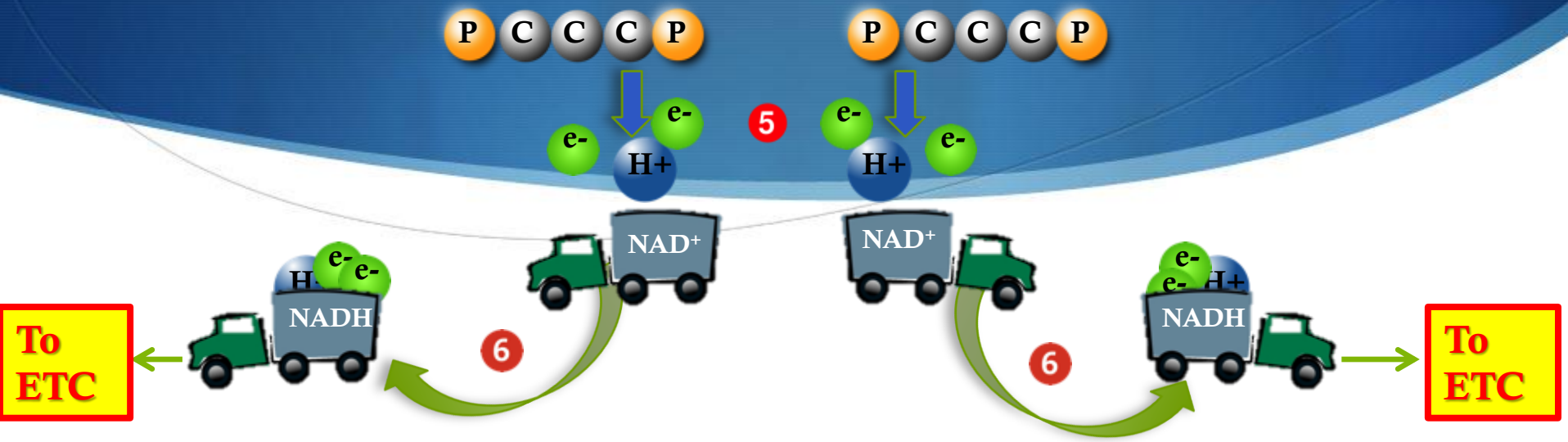




3 A high energy **phosphate** molecule joins to each of these two molecules.

4 Releasing two hydrogen ions and four high-energy **electrons**.

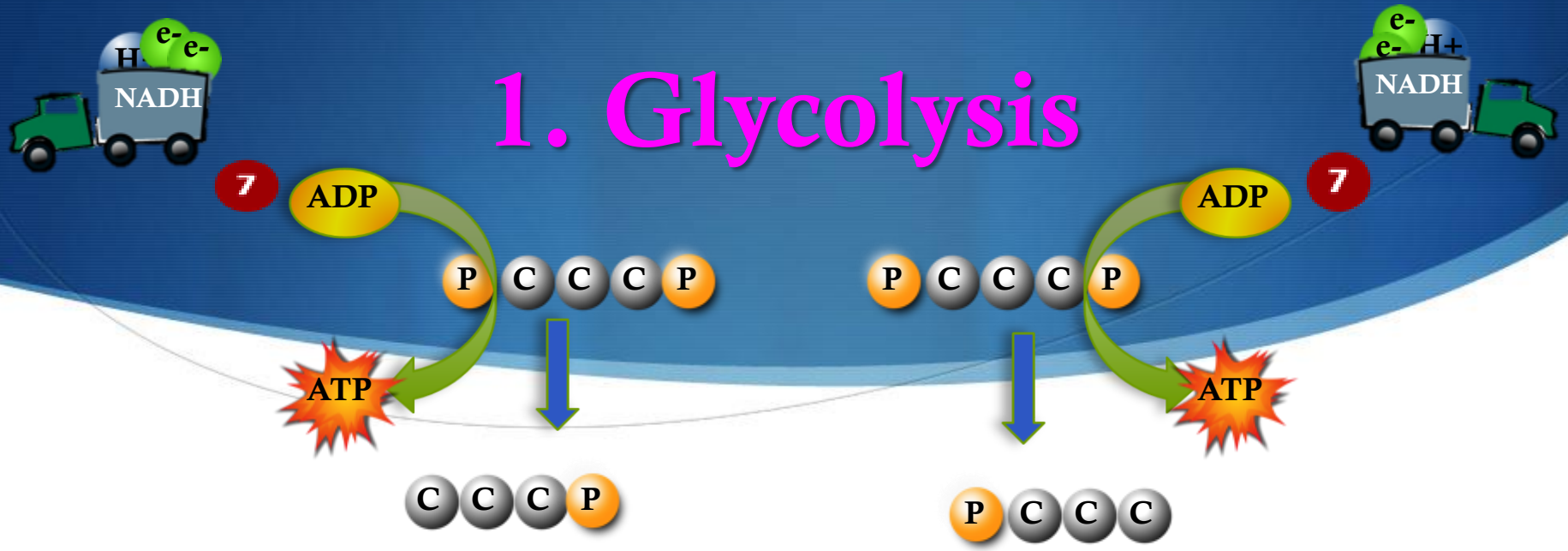
1. Glycolysis



5 High energy electrons & hydrogen ions are passed to two **NAD+ molecules** (electron acceptors).

6 When each **NAD+** **accepts the electrons and hydrogen ion**, it is **reduced** from **NAD+ to NADH**.

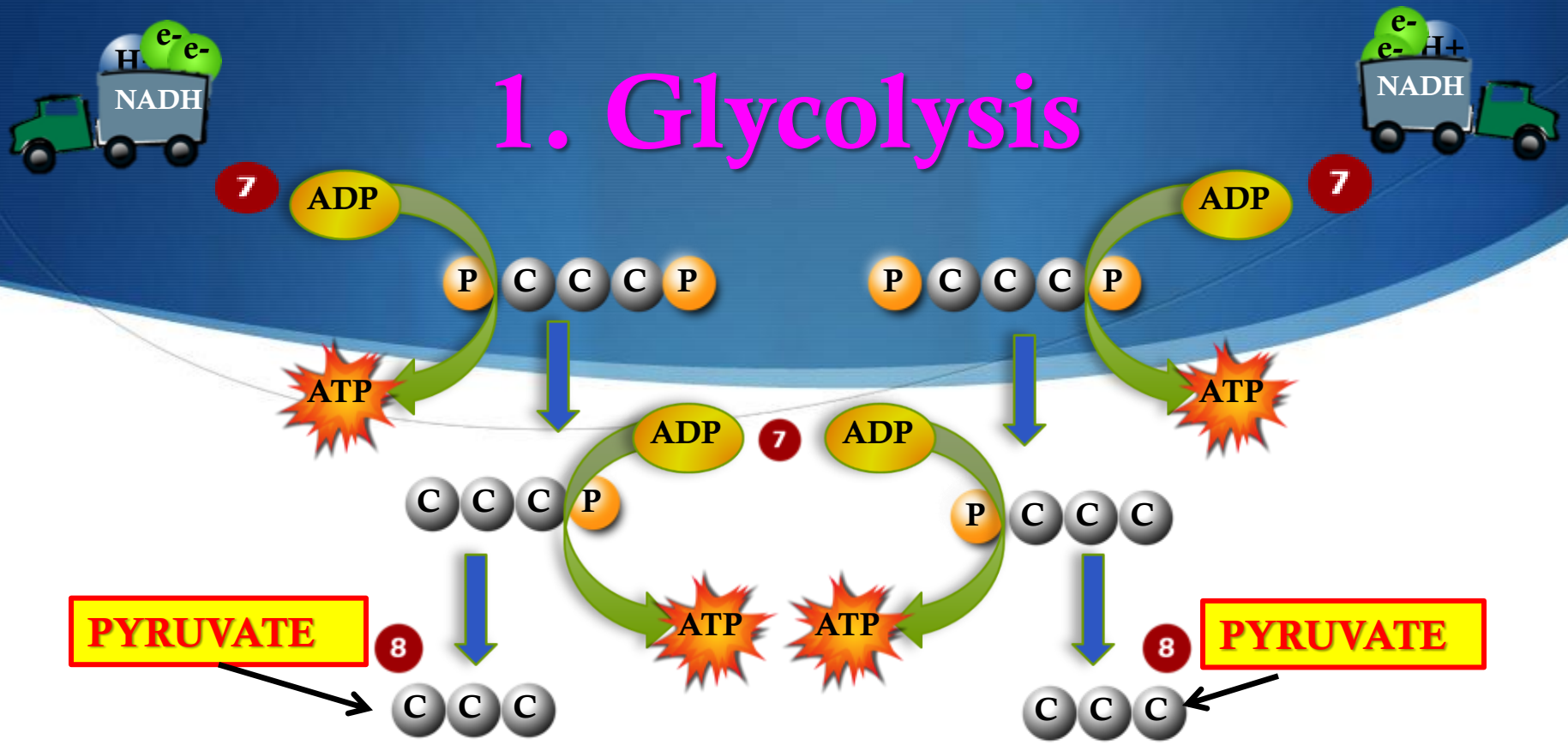
✓ NAD+ is an **electron acceptor**. It carries electrons & hydrogen to the **Electron Transport Chain (ETC)**.



7 **Direct Phosphorylation**:

ADP molecules join with the **phosphates** on each end of the split glucose molecule forming **ATP** molecules.

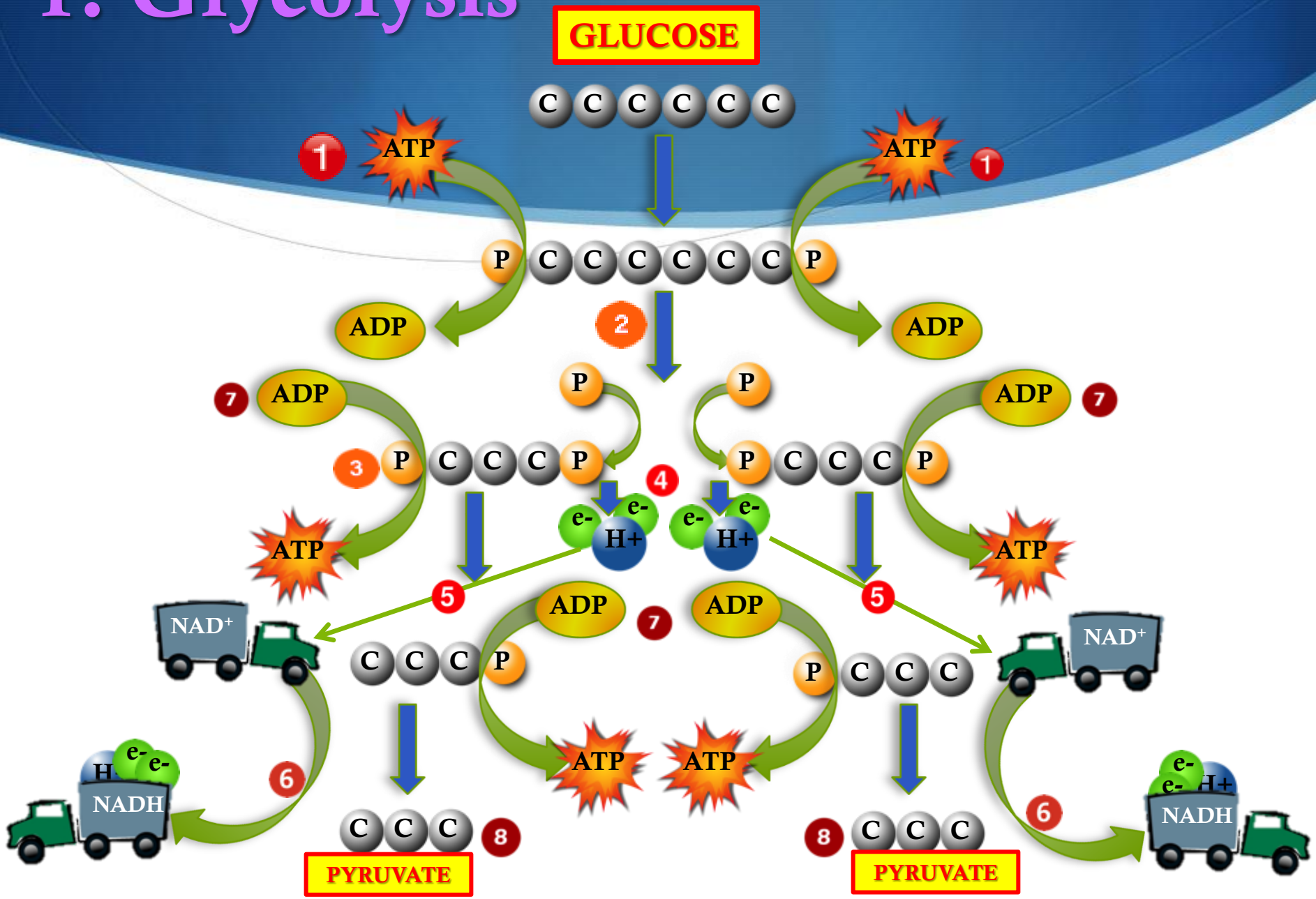
1. Glycolysis



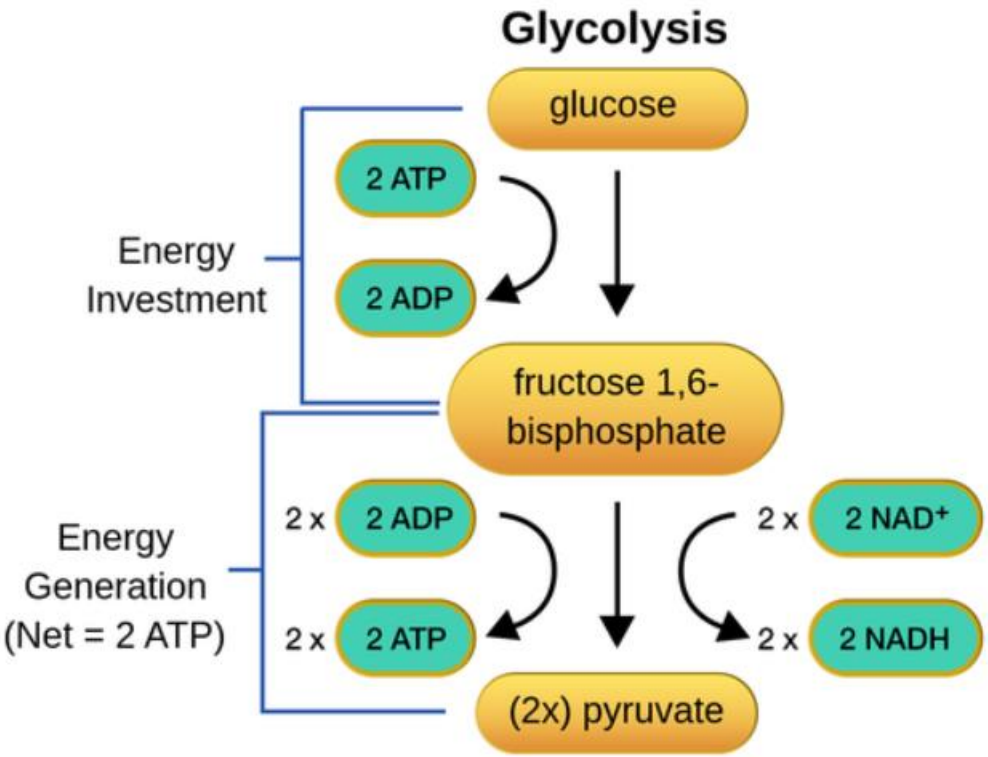
7 **Direct Phosphorylation**

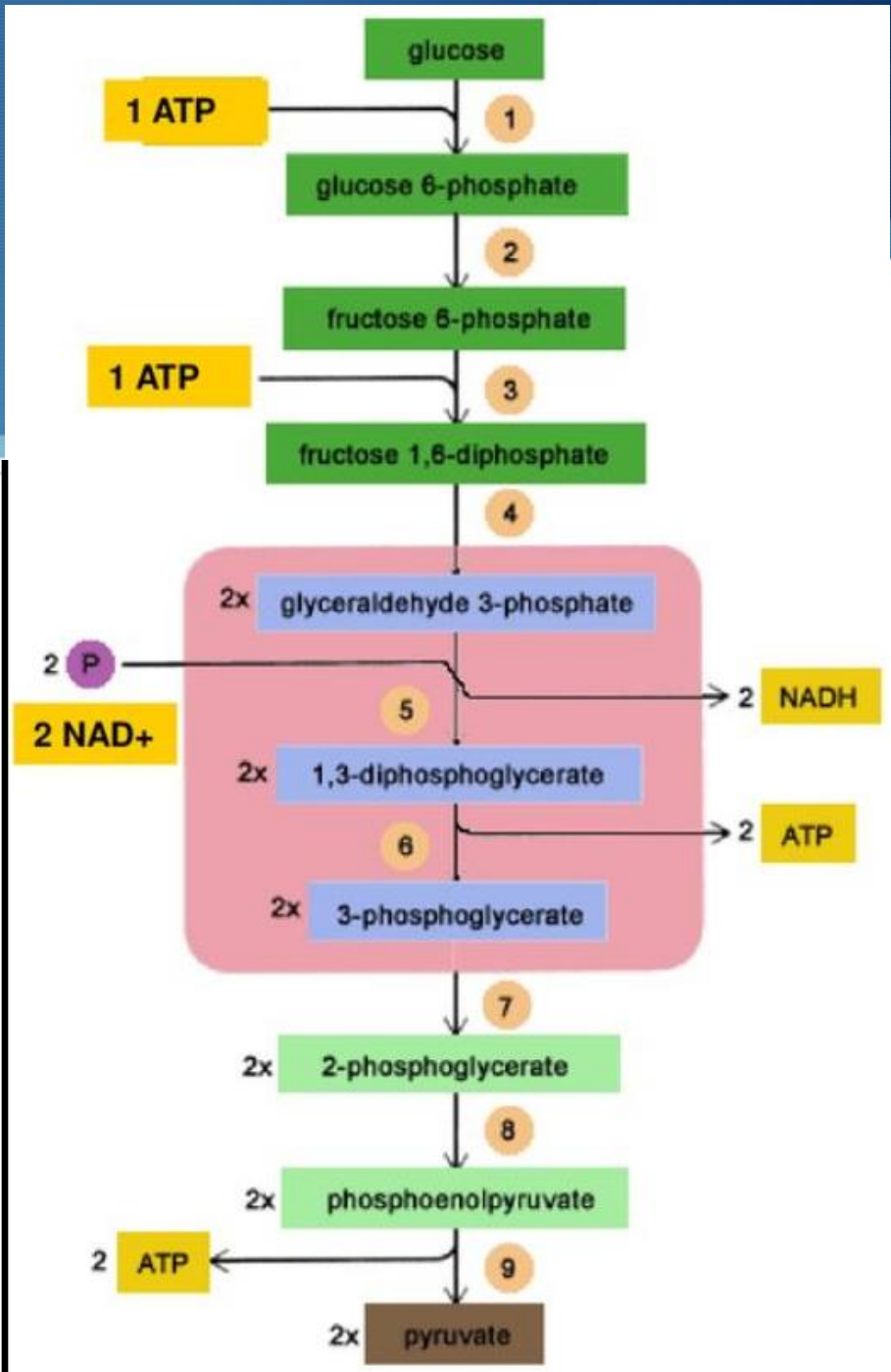
8 When the phosphorus is taken off each end of the molecule, **PYRUVATE** is formed.

1. Glycolysis



1. Glycolysis Summary





TRY IT

Step 1: Glycolysis

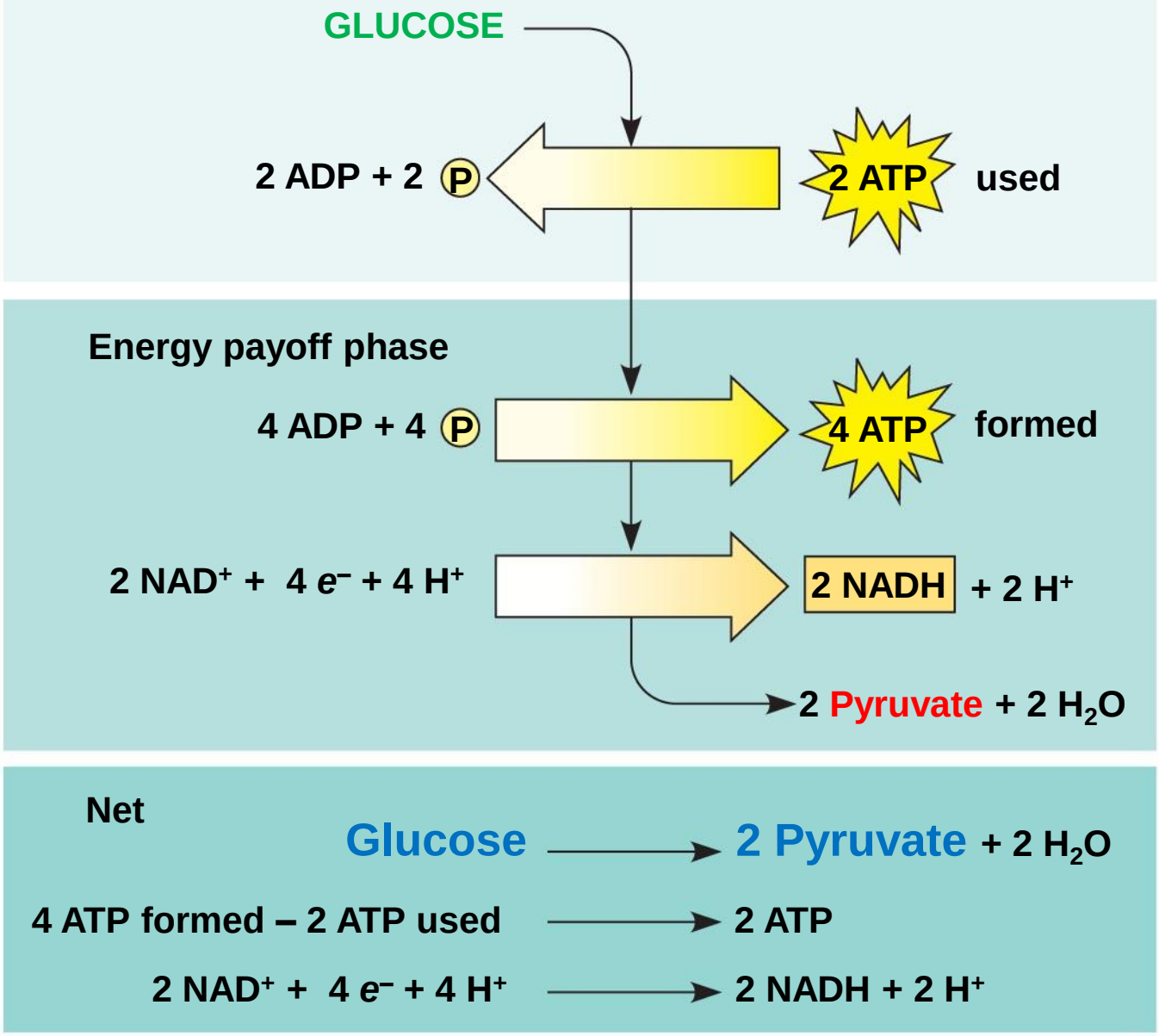
1. What is it?
2. Where does it occur?
3. What is used?
4. What energy molecule is produced?
5. What are the chemical by-products of the reaction?

TRY IT

Step 1: Glycolysis

1. What is it?
   - **Breaking down of glucose**
2. Where does it occur?
   - **Cell cytoplasm**
3. What is used?
   - **Glucose**
4. What energy molecule is produced?
   - **Net 2 ATP (2 used, 4 produced)**
5. What are the chemical by-products of the reaction?
   - **2 pyruvate (pyruvic acid), 2 NADH**

Glycolysis - Energy investment phase



Net

Glucose → **2 Pyruvate** + 2 H_2O

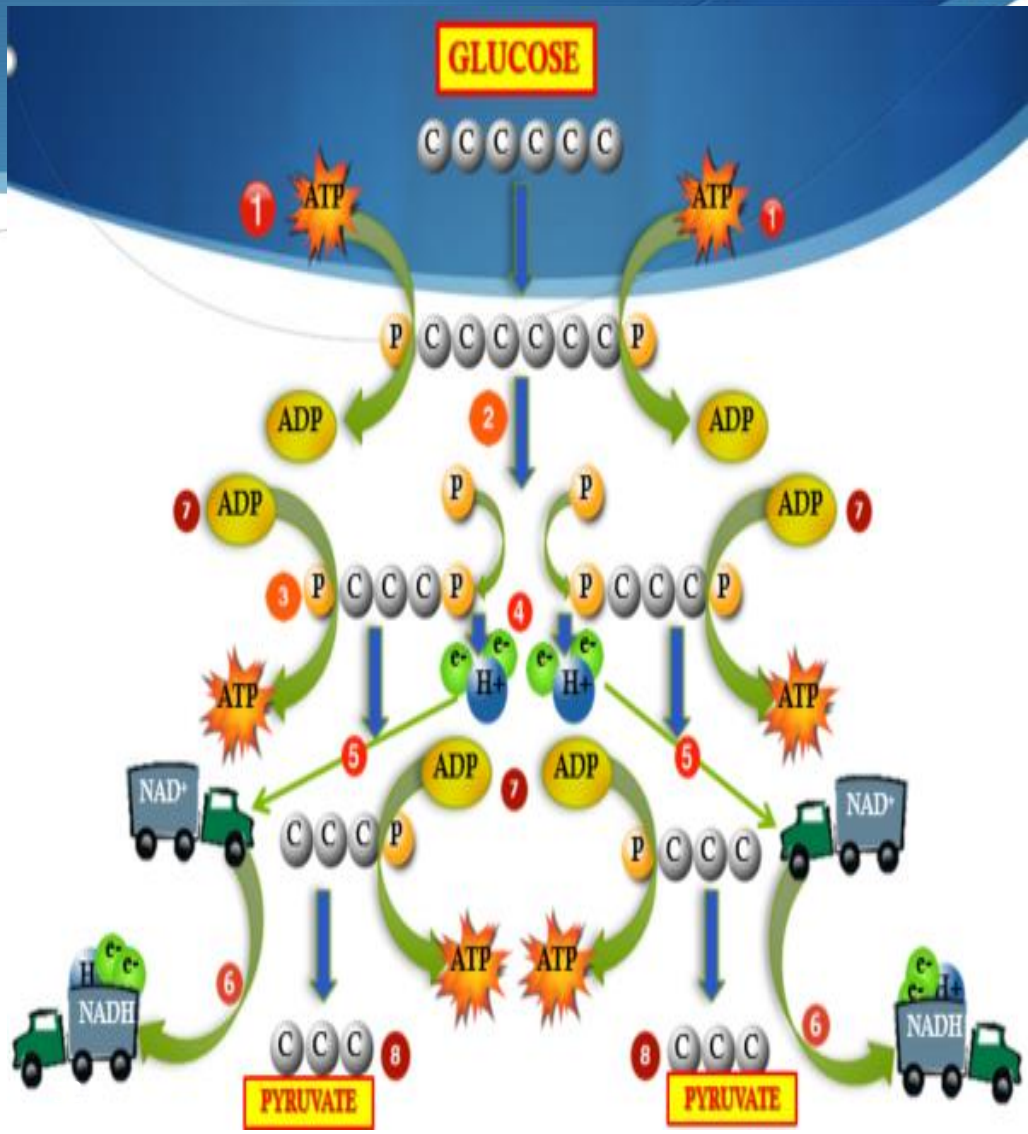
4 ATP formed – 2 ATP used → 2 ATP

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

TRY IT

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 = _____**



TRY IT

1. Glycolysis Summary

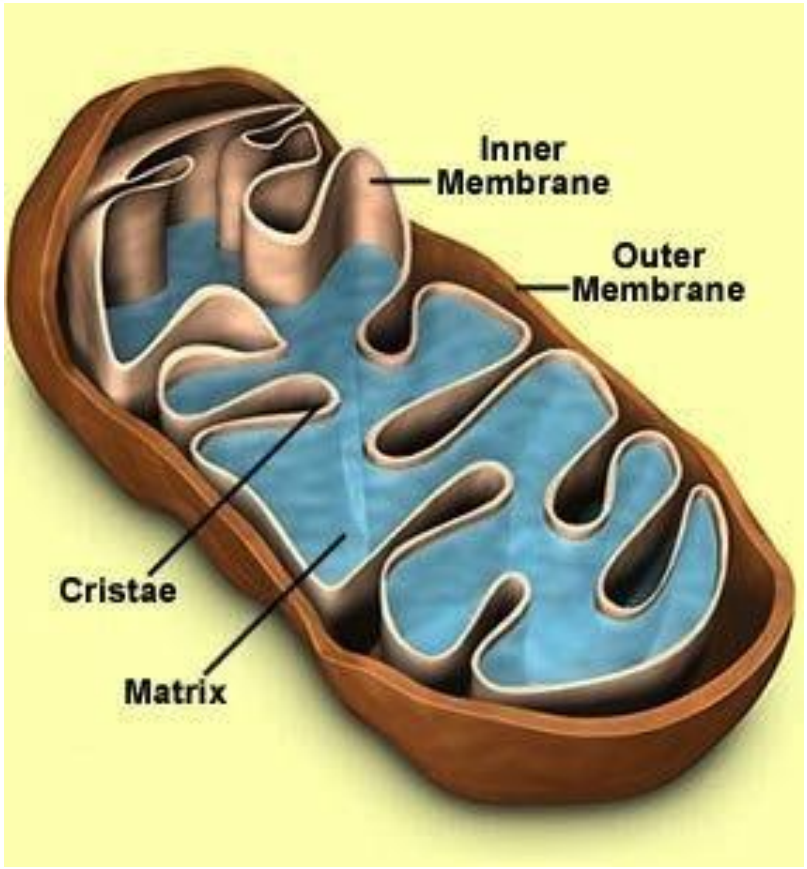
- ✓ Takes place in the **Cytoplasm**
- ✓ **Anaerobic** (no oxygen)
- ✓ Glucose "splits" into two 3-carbon molecules of **Pyruvate**
- ✓ NAD+ is **reduced** by gaining electrons & produces **2 NADH**
- ✓ **Phosphorylation** to make 4 ATP
- ✓ Requires an **input** of 2 ATP
- ✓ **Net ATP production = 2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

All Steps of Cell Respiration occur in mitochondria except Glycolysis

QUICK CHECK

Review of Mitochondria Function

- "_____" of the cell: They produce almost all of the _____ the cell uses.
- Possess their own _____.
- Can _____ independent of the cell.
- All cells have mitochondria (_____ & _____).

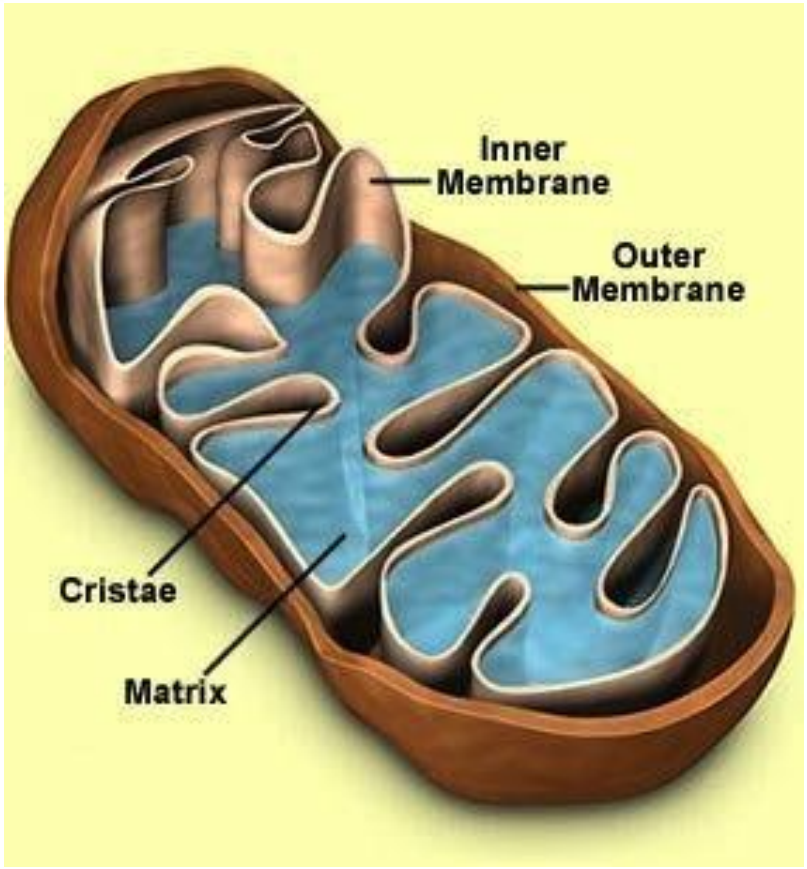


All Steps of Cell Respiration occur in mitochondria except Glycolysis

QUICK CHECK

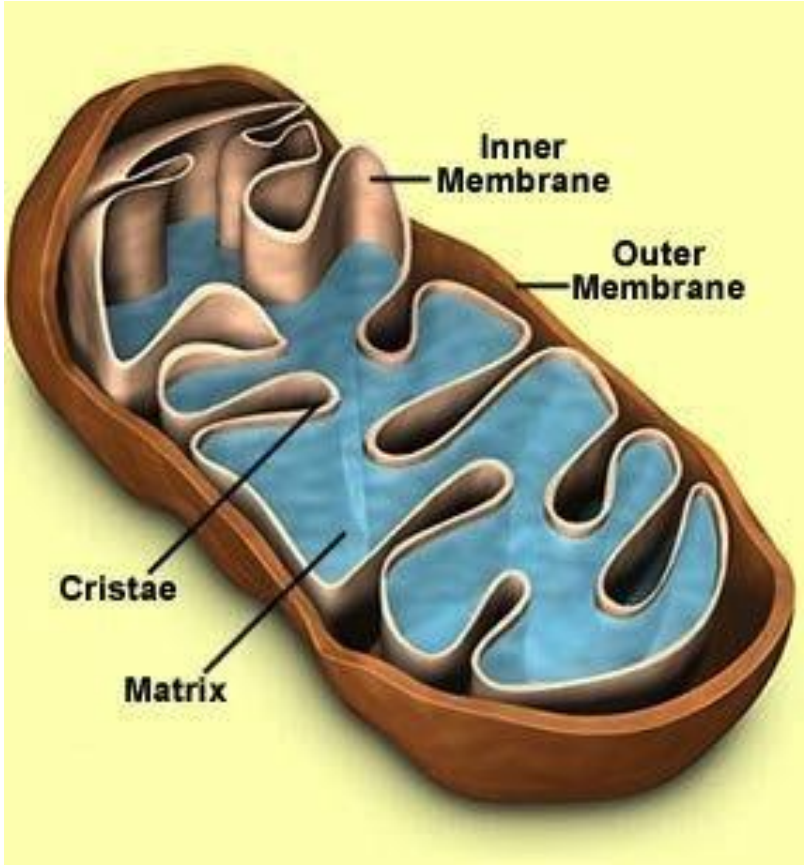
Review of Mitochondria Function

- "Powerhouse" of the cell: They produce almost all of the ATP the cell uses.
- Possess their own DNA.
- Can replicate independent of the cell.
- All cells have mitochondria (prokaryotic & eukaryotic).



Review of Mitochondria Structure

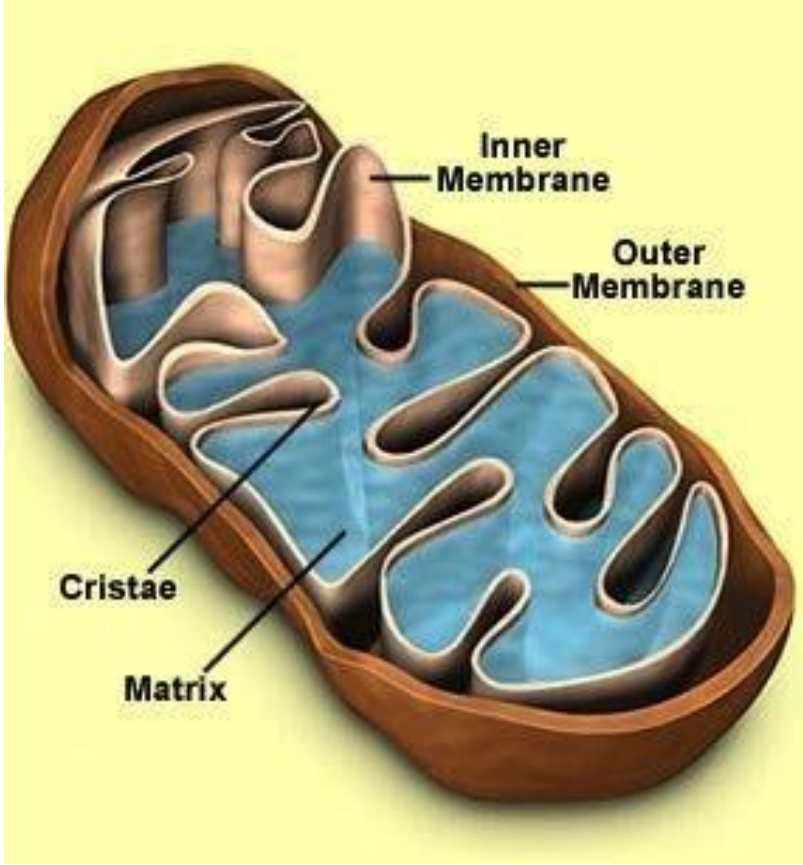
- Double Membrane System
  - Smooth Outer membrane.
  - Folded Inner membrane.
  - Folds called Cristae.
  - Space inside Cristae called the Matrix.



The molecules that produce most of the ATP are embedded in the Inner Membrane.

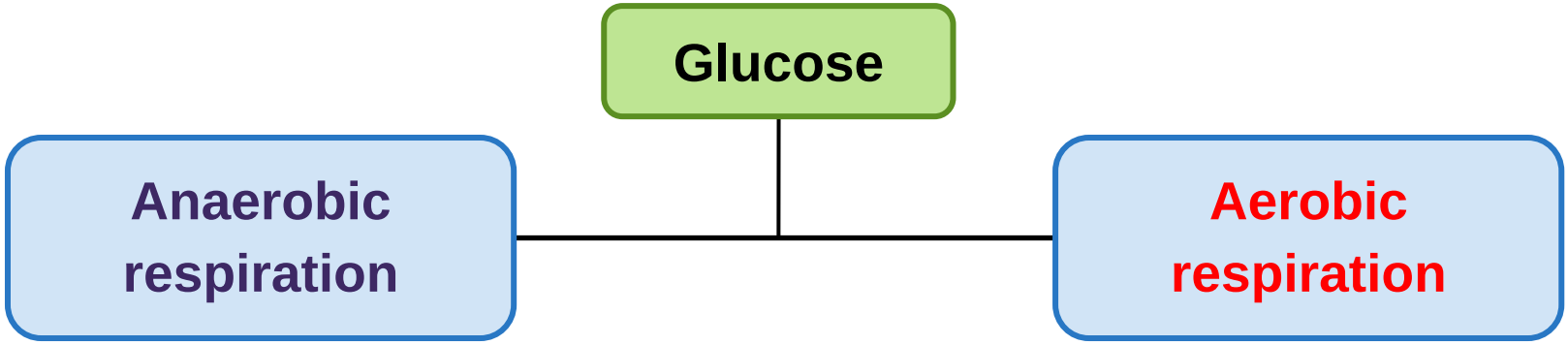
Review of Mitochondria Structure

- **Outer Compartment**: Space between inner and outer membrane.
  - **Hydrogen ions** accumulate here.



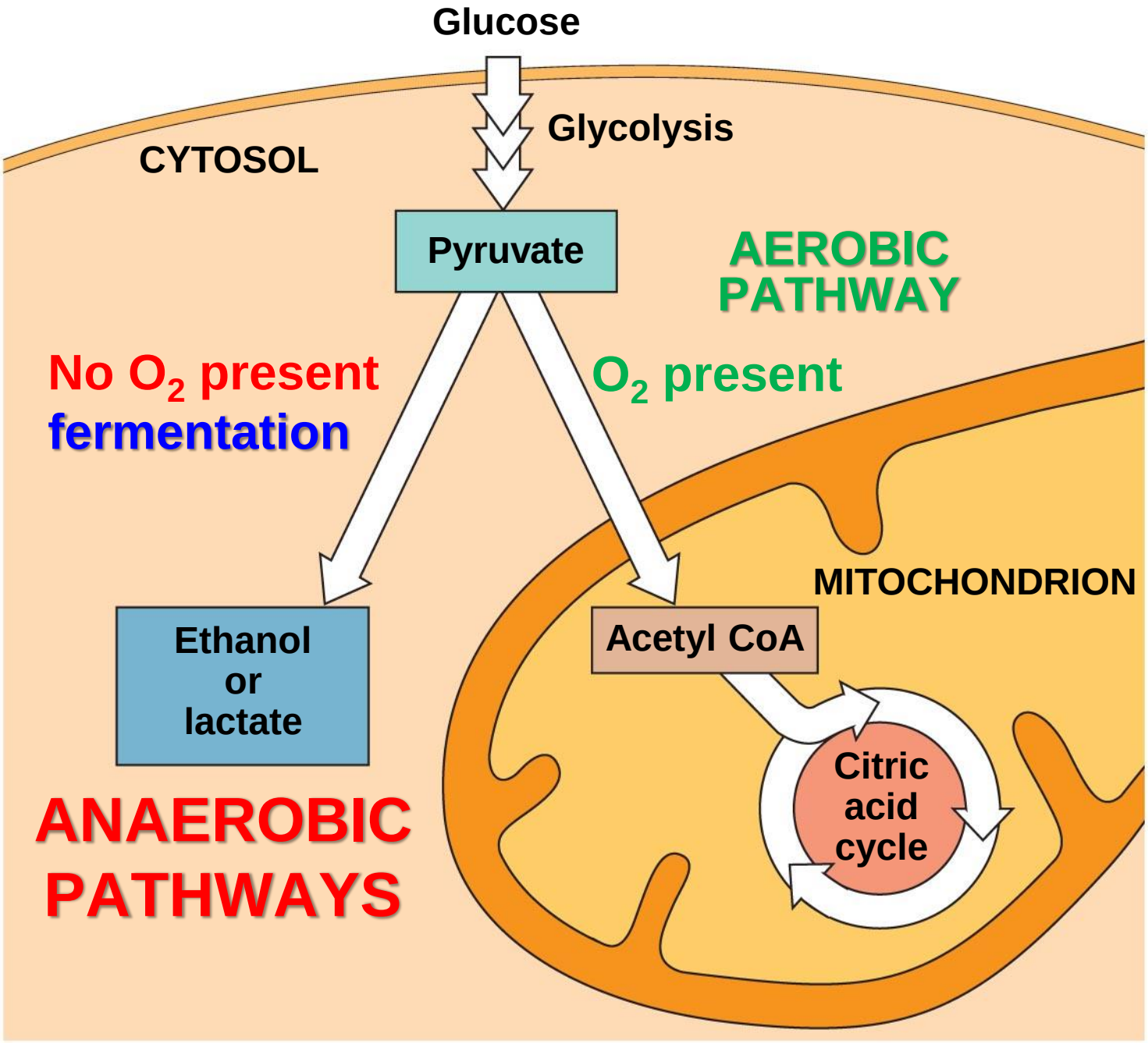
Process of Cellular Respiration

Cell Respiration can take one of two pathways, depending upon whether **OXYGEN is present or not**:



- A cellular respiration reaction that requires the **absence** of **oxygen.**

- A cellular respiration reaction that requires the **presence** of **oxygen.**


Glucose
Glycolysis
CYTOSOL
Pyruvate
AEROBIC PATHWAY
No O_2 present
fermentation
O_2 present
MITOCHONDRION
Ethanol or lactate
Acetyl CoA
Citric acid cycle
ANAEROBIC PATHWAYS

After Glycolysis … Summary

ANAEROBIC PATHWAYS

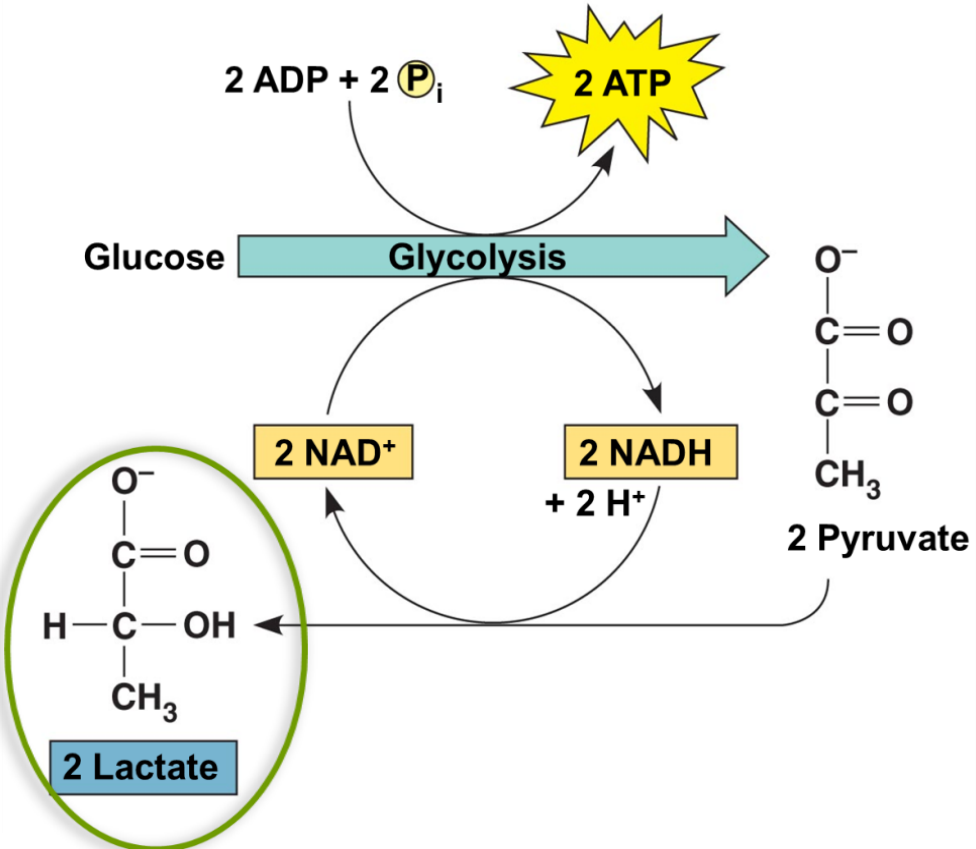
- Metabolism of glucose **WITHOUT OXYGEN** to generate **ATP.**
- Generates **ATP** much **more quickly** than aerobic.
- Preferred source of ATP production when energy is needed in short bursts (**Sprinting**).
- **Fermentation**

AEROBIC PATHWAYS

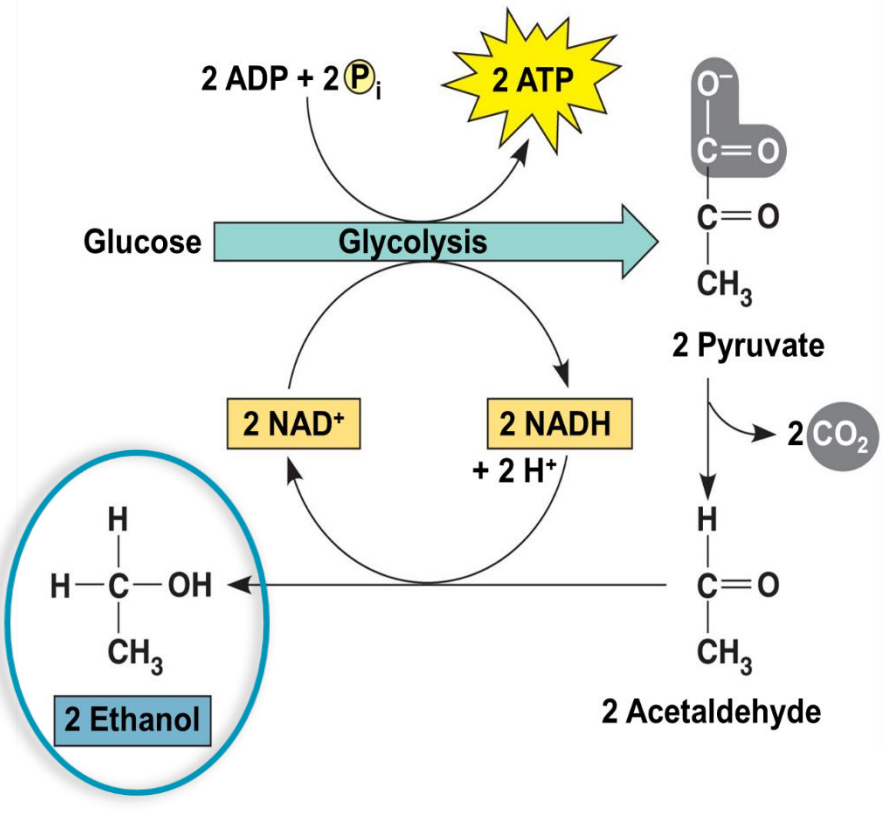
- Metabolism of glucose **USING OXYGEN** to generate **ATP.**
- **OXYGEN** is **Final Electron Acceptor.**
- Generates **much more ATP per molecule of glucose** metabolized than anaerobic respiration (**Efficient**).
- **Krebs Cycle (Citric Acid)**
- **Electron Transport Chain (ETC)**

Two Anaerobic Pathways

Lactic Acid Fermentation

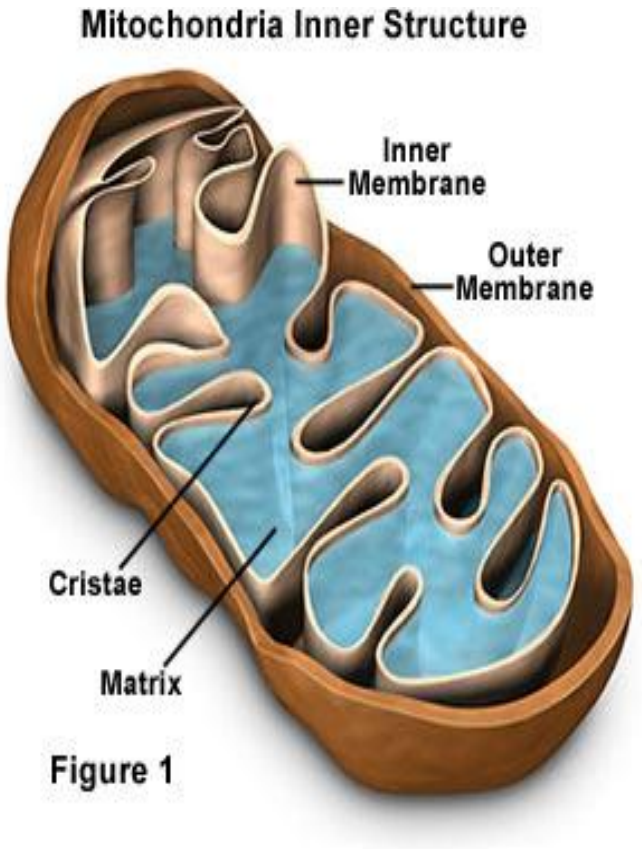


Alcohol Fermentation



Aerobic Processes

- If **O_2 is present** following glycolysis, **pyruvate** is modified and enters the mitochondria.
- Here pyruvate is broken down completely into **CO_2 → Krebs Cycle (Citric Acid Cycle)**.
- Energy storage molecules like **NADH** and **ATP** are produced.
- This is why the **mitochondria** is called the **powerhouse of the cell**.



Aerobic Processes

- In **PROKARYOTES**, if **O_2 is present** following glycolysis, **pyruvate** is modified and remains in the **cytoplasm**.
- Here pyruvate is broken down completely into **CO_2** → **Krebs Cycle** .
- Energy storage molecules like **NADH** and **ATP** are produced.

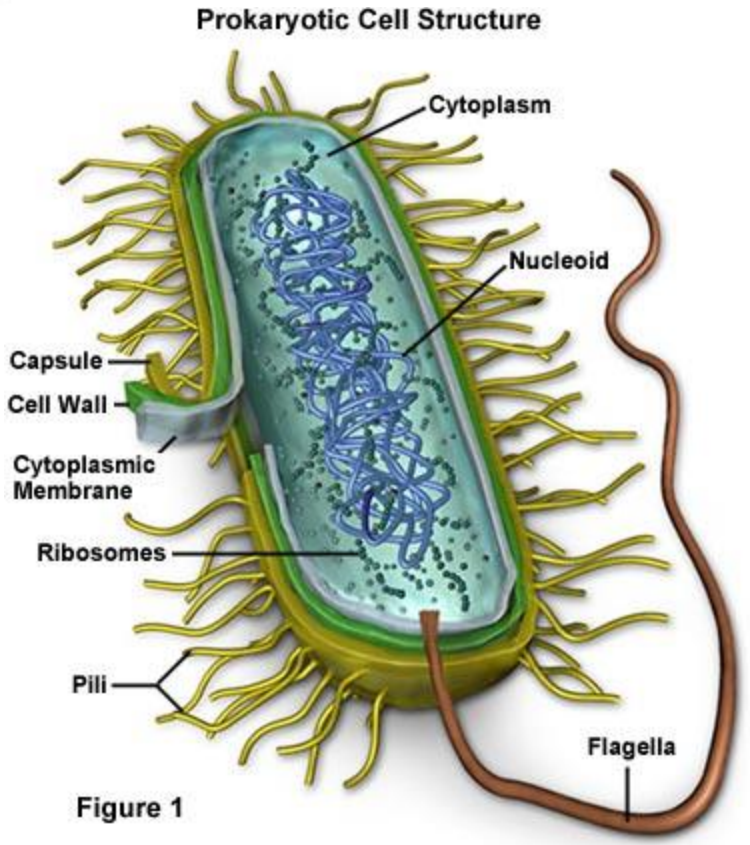
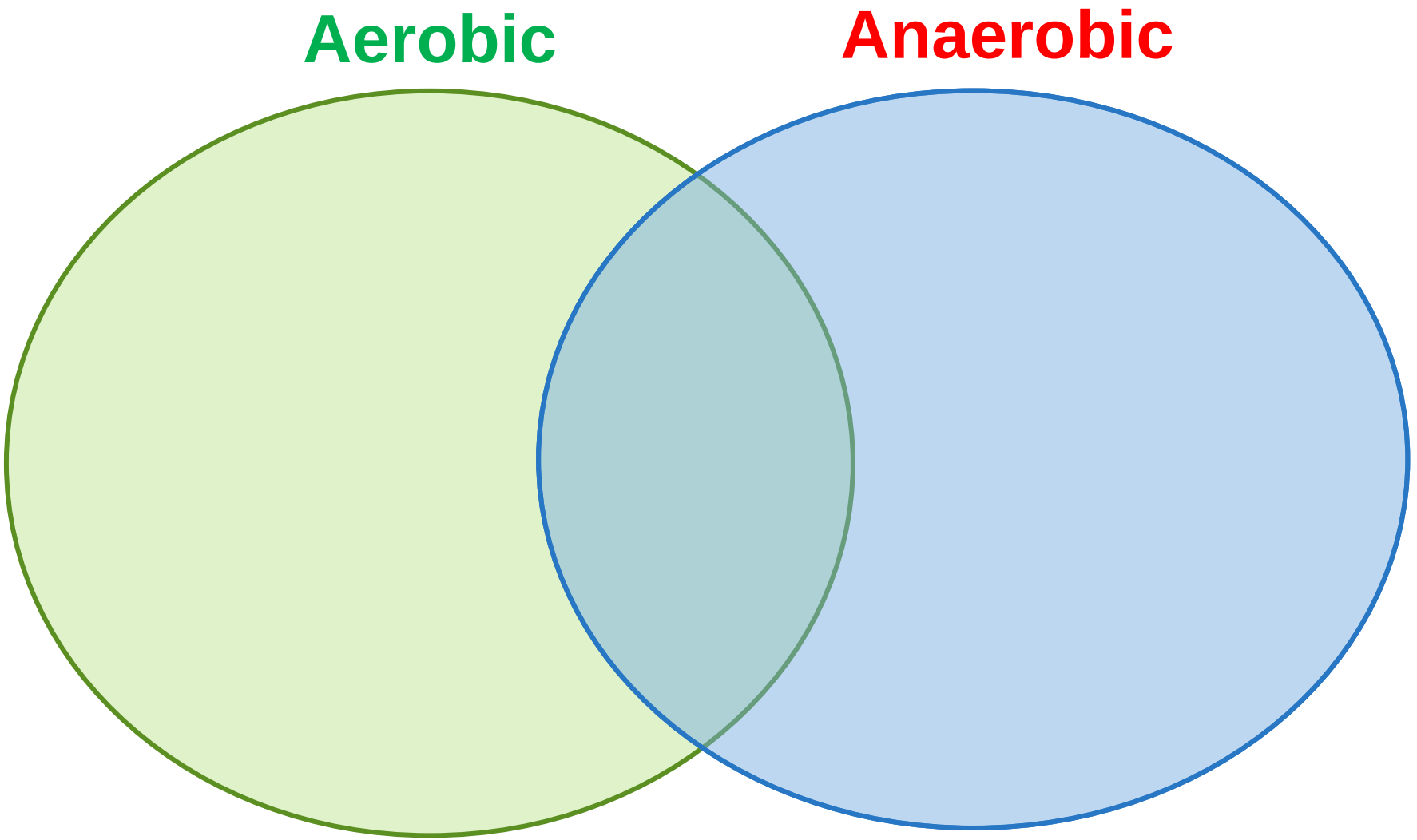


Figure 1

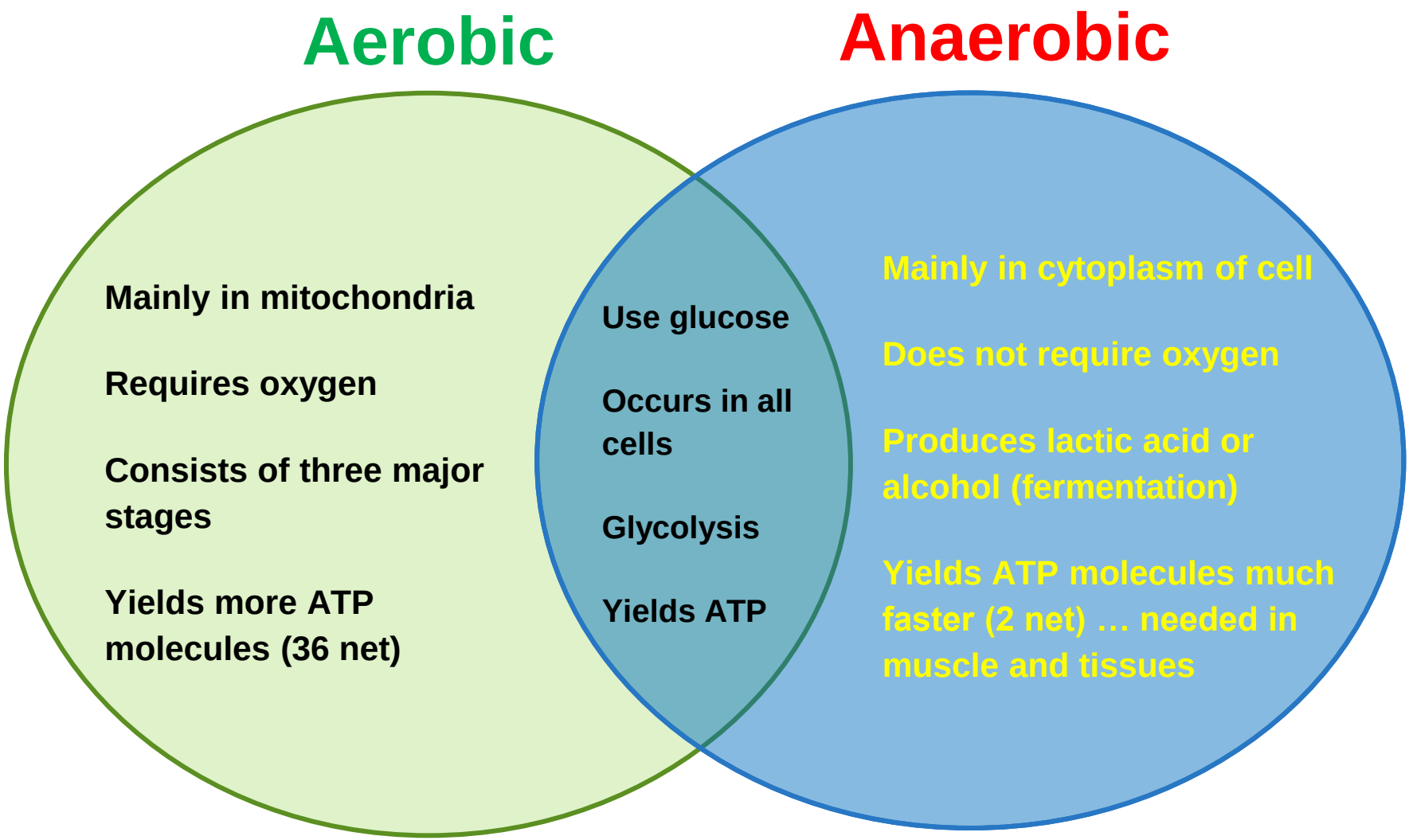
Complete the Venn Diagram:
Aerobic vs. Anaerobic Respiration

QUICK CHECK



Complete the Venn Diagram:
Aerobic vs. Anaerobic Respiration

QUICK CHECK



TRY IT

Complete the table, comparing Aerobic & Anaerobic Respiration

	Aerobic Respiration	Anaerobic Respiration
Oxygen	Required	NOT Required
Location	Mitochondria	Cytoplasm
Steps	Glycolysis Kreb's Cycle Electron Transport Chain	Glycolysis Fermentation Alcohol or Lactic Acid
Total ATP Produced	Produces 36 ATP	Produces 2 ATP

TRY IT

Complete the table, comparing Aerobic & Anaerobic Respiration

	Aerobic Respiration	Anaerobic Respiration
Oxygen	Is required	Is not required
Location	Occurs in the mitochondria	Occurs in the cytoplasm
Steps	• Glycolysis • Citric acid cycle • Electron Transport Chain	Glycolysis Fermentation • Lactic acid • Alcohol
Total ATP Produced	Produces 36 ATP	Produces 2 ATP (no additional ATP)