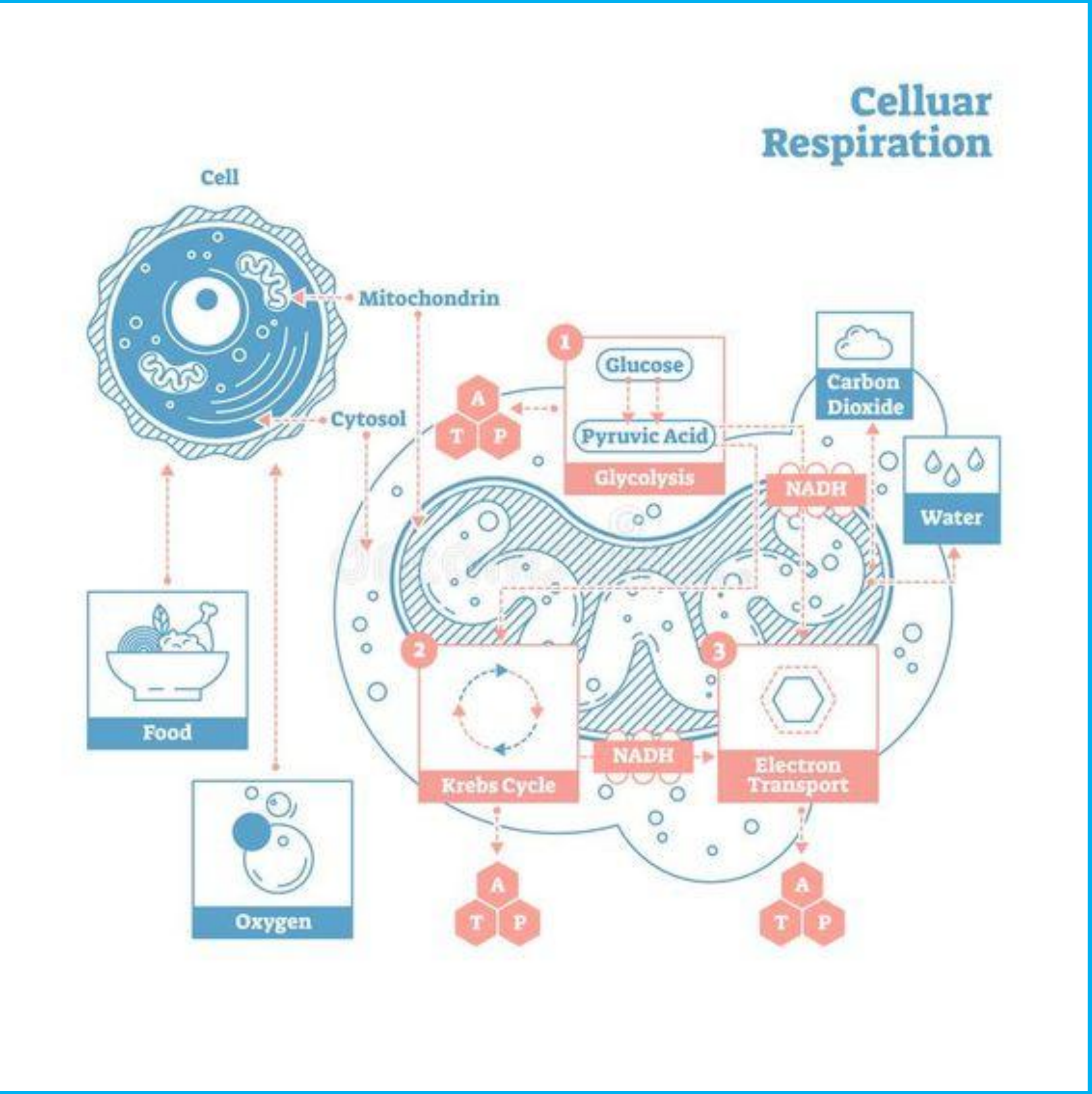


Chapter 7
Energy & Metabolism

Course: BIO 101,
Introduction to Biology

What is Energy

- Energy is the ‘capacity to do work’.
- Anything our body does, it needs a certain level of energy to function. Examples of activities that require energy include:

✔ walking

✔ running

✔ exercising

✔ doing homework

✔ eating

✔ sleeping

✔ breathing

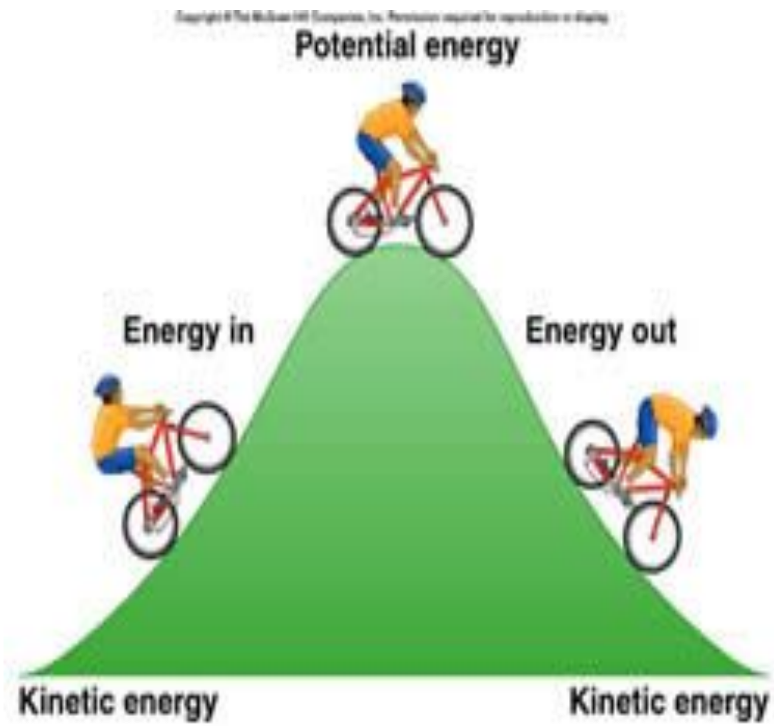





Energy exists in different forms!

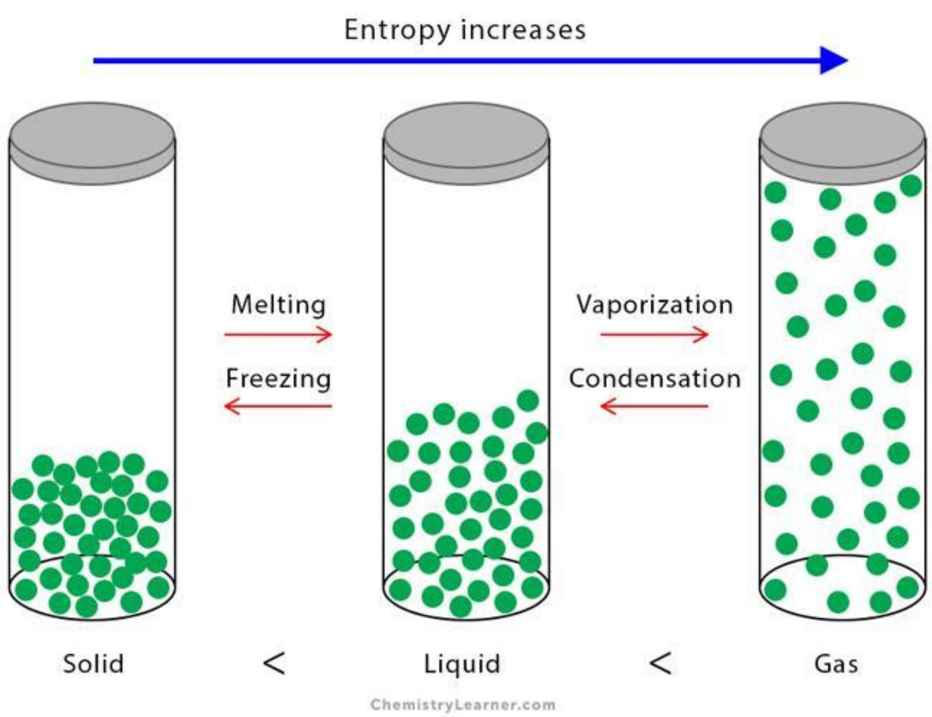
- **Potential energy**: energy that is stored in an object at rest, based on the position it is in.
  - ✔ E.g. A bike resting on top of a hill

- **Kinetic energy**: Energy used by a moving object
  - ✔ E.g. A bike moving up and down a hill.



Thermodynamics

- Heat is a form of energy, called thermal energy.
- The study of the conversion of thermal energy to and from other types of energy is called thermodynamics.
- All metabolic reactions release some amount of heat.



- **First Law of Thermodynamics**
  Energy cannot be created or destroyed, can be converted from one form to another.

- **Second Law of Thermodynamics**
  Energy tends to spread out or disperse spontaneously from high energy forms to forms lower in energy. The tendency of entropy to increase is the second law of thermodynamics.

- **Entropy**
  Measure of how much the energy of a particular system has become dispersed.

Metabolism

Metabolism is collectively all the chemical reactions that take place within each cell of a living organism for,

- providing energy to vital processes
- for synthesizing new organic material.

- Cells store energy by building organic molecules and retrieve energy by breaking them down.

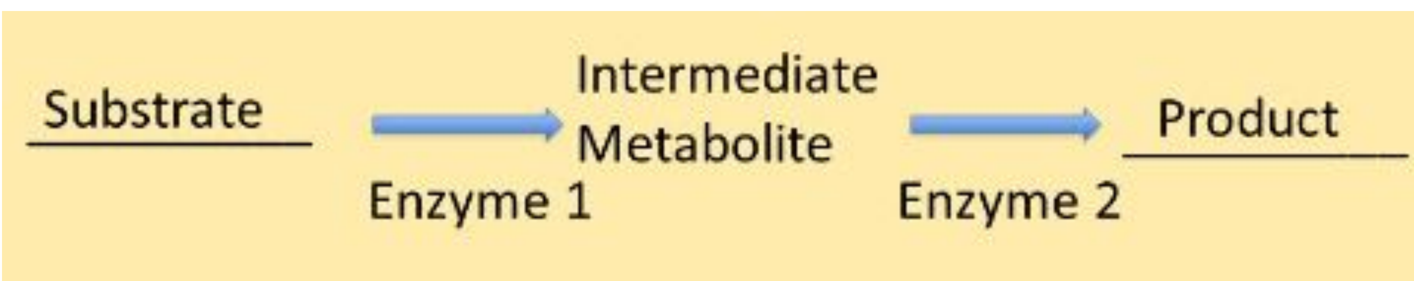


Fig: A simple Metabolic pathway

Participants in metabolic pathways

A reaction occurs when components undergo the following changes:

Substrates: starting components that are being converted in a chemical reaction; also called reactants

→

Intermediates: components that have been converted from substrates and are converted further into another component

→

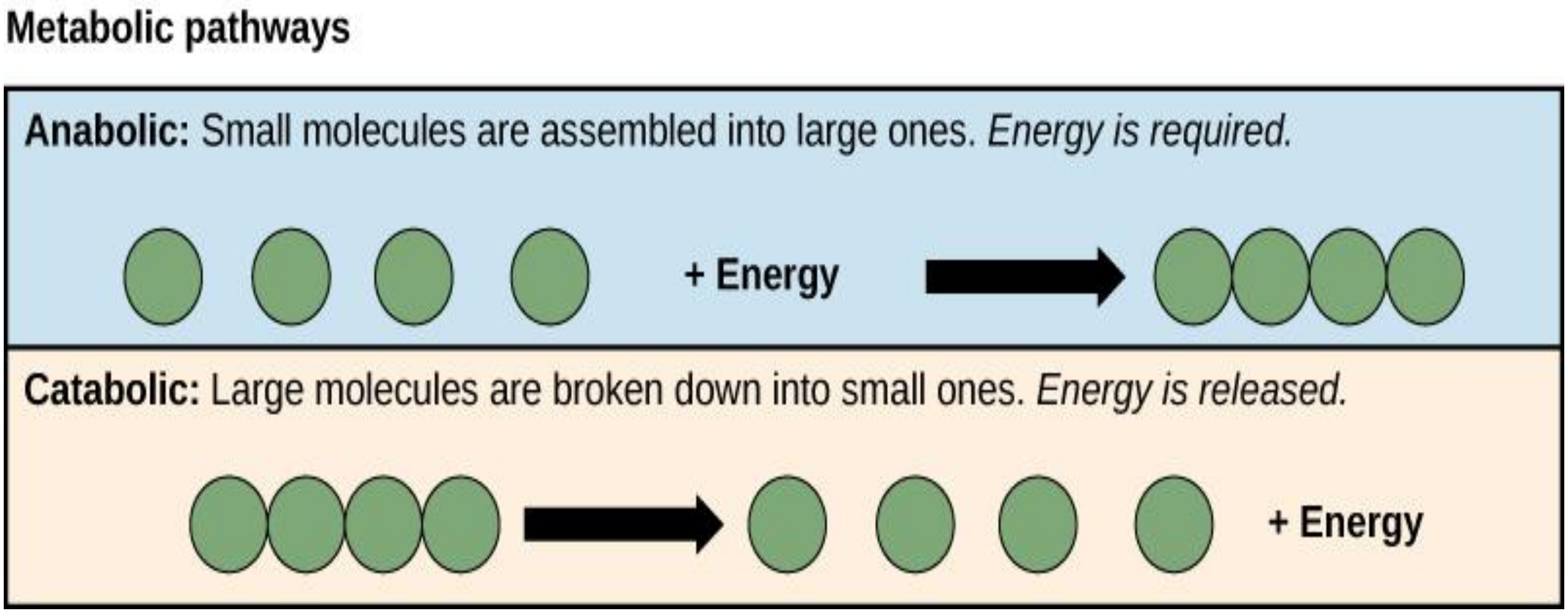
End products: the final products formed at the end of the reaction

Several biological molecules assist in completion of a reaction, which are:

- **Energy Carriers**: ATP
- **Enzymes**: Biological molecules that speed up a reaction
- **Cofactors**: Non-protein chemical compounds that aid in an enzyme’s activity

Types of Metabolic pathways

- Anabolic Pathway
- Catabolic Pathway



Energy in the Molecules of Life

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Chemical Energy: Every chemical bond holds a certain amount of energy.

- This is the amount of energy required to break the bond, and it is also the amount of energy released when the bond forms.
- The particular amount of energy held by a bond depends on which elements are taking part in it. For example, two covalent bonds—one between an oxygen and a hydrogen atom in a water molecule, the other between two oxygen atoms in molecular oxygen (O_2)—both hold energy, but different amounts.

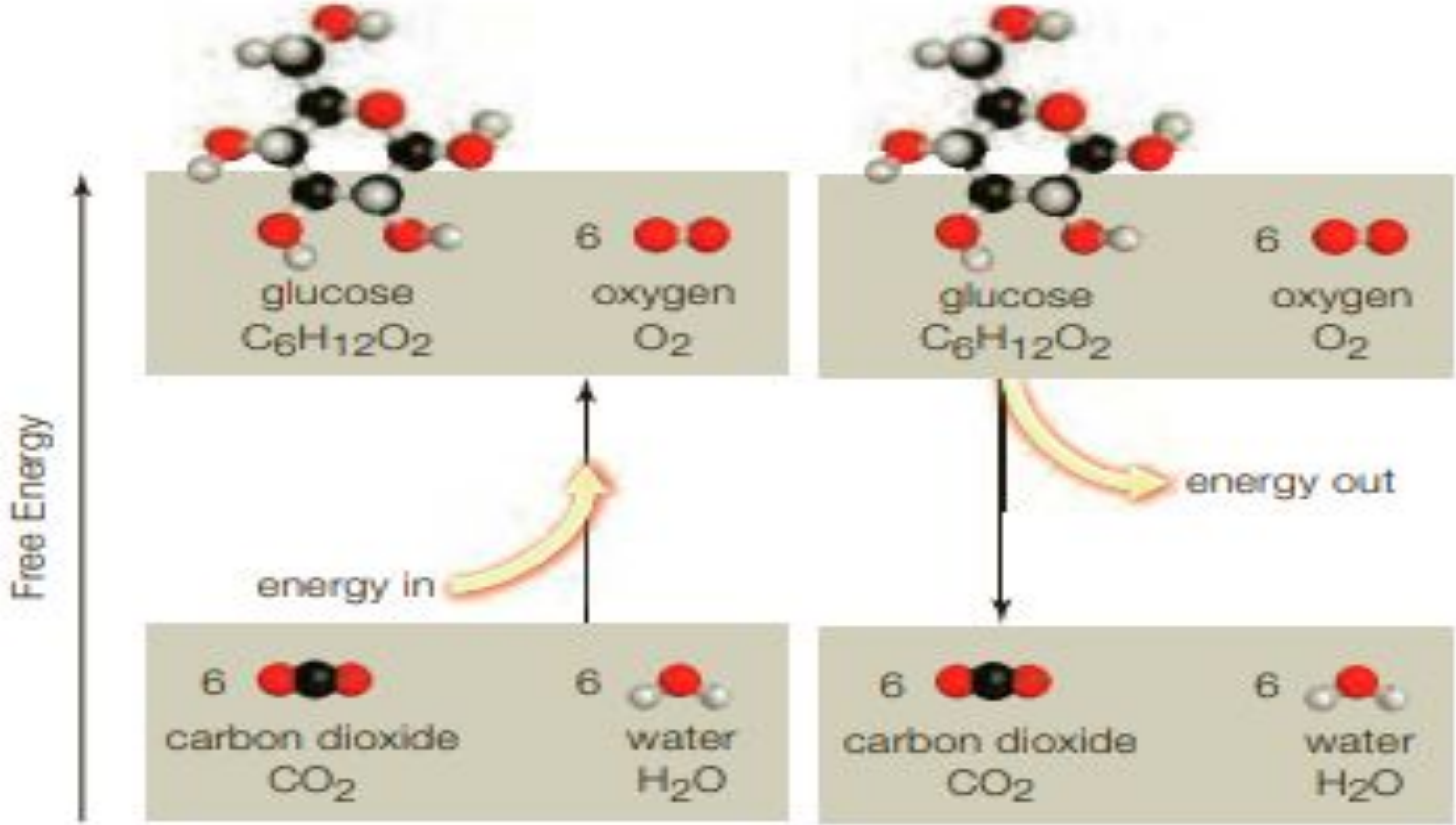
- Energy changes in living body/cells occurs mostly via two types reactions:

1. Endergonic Reactions

- Energy input required.
- Product has more energy than starting substances.
- Anabolic reactions are endergonic.
- Energy **"in"**

2. Exergonic Reactions

- Energy is released.
- Products have less energy than starting substance.
- Catabolic reactions are exergonic.
- Energy **"out"**



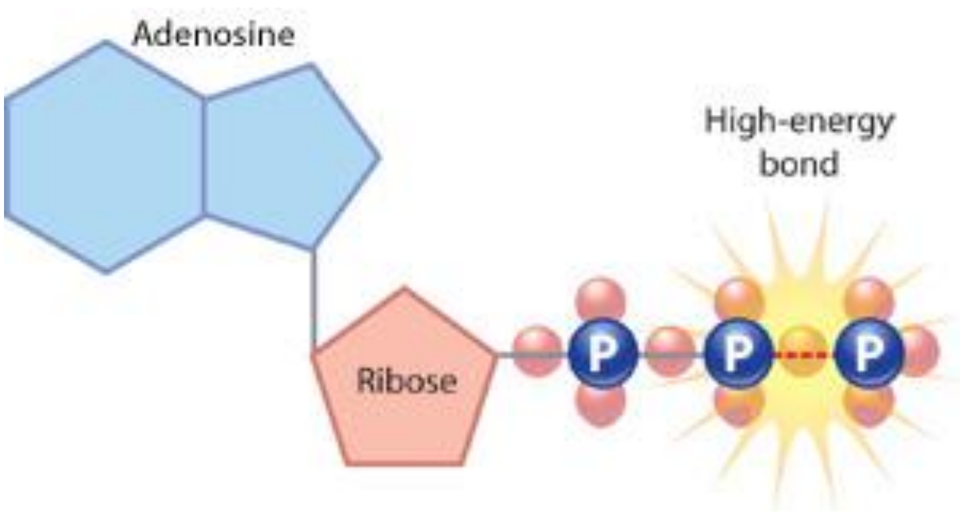
A Endergonic reactions convert molecules with lower free energy to molecules with higher free energy, so they require a net energy input.

B Exergonic reactions convert molecules with higher free energy to molecules with lower free energy, so they end with an energy release.

Figure 5.6 The ins and outs of energy in chemical reactions.

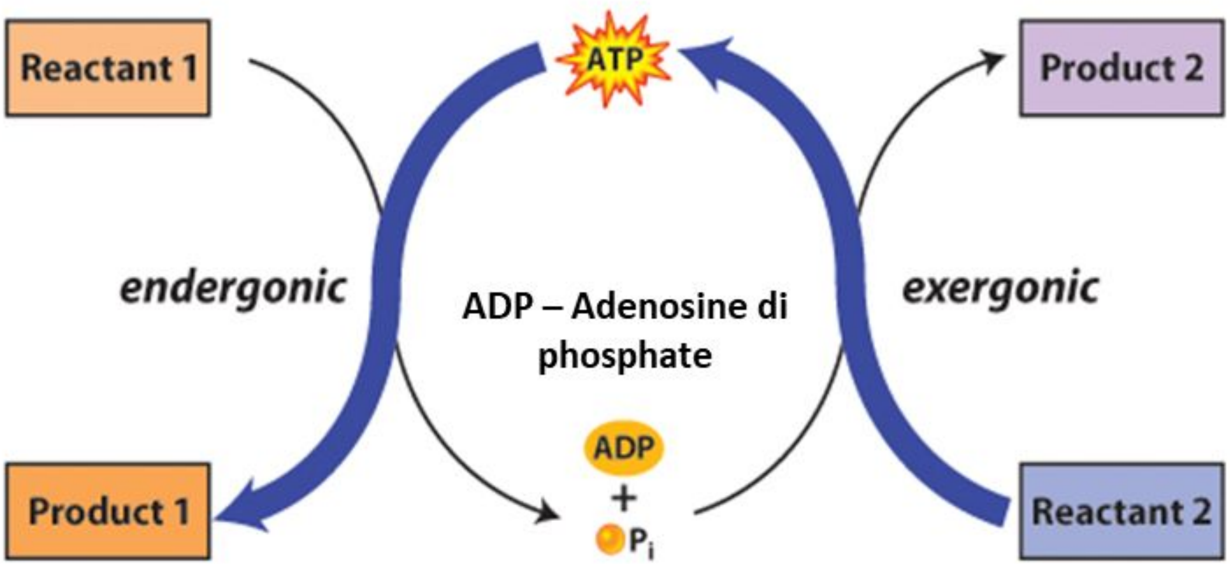
What is (ATP)?

- Adenosine triphosphate
- ATP is the energy-carrying molecule found in cells of living organisms.
- It is composed of :
  - One adenosine (adenine + ribose sugar) & three phosphate groups
  - One adenosine + two phosphate=ADP (Adenosine diphosphate)



The Role of ATP?

- Cells "earn" energy (ATP) in exergonic reactions
- Cells "spend" energy (ATP) in endergonic reactions

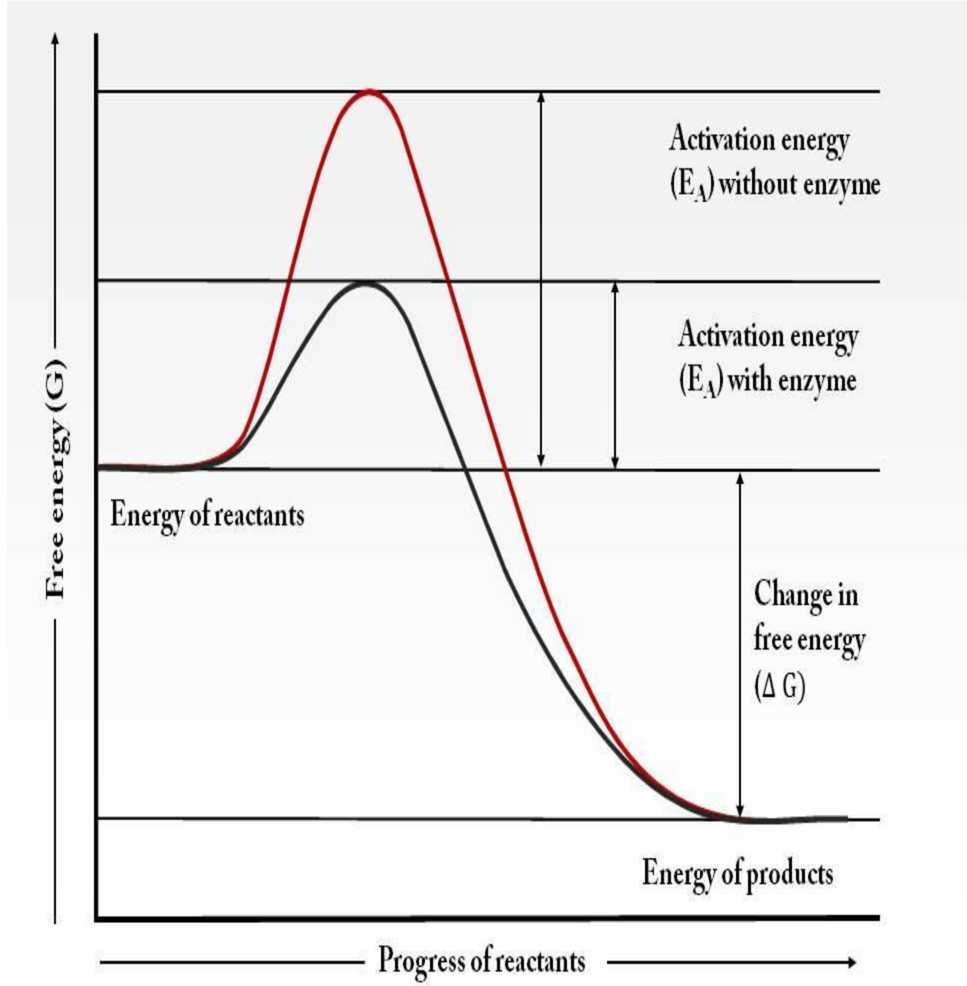


Phosphate

Activation Energy

- For a reaction to occur, an energy barrier must be overcome.
- Activation energy is the minimum amount of energy needed for a chemical reaction to occur
- Its like a hill that reactants must climb before they can coast down the other side to become products
- Enzymes make the energy barrier (activation energy) smaller, hence the reaction runs faster.
- Both endergonic and exergonic reactions have activation energy, but the amount varies with the reaction.

Enzymes & Activation Energy



Membrane Transport Mechanism

- Nutrients and other compounds are required for energy production, for cell growth and normal activities. To utilize the compounds, cell must uptake nutrients from the environment.

- Uptake mechanisms must be specific- that is the necessary substances, not others, must be acquired. So, special transport systems are required for nutrient uptake.

- Transport systems are located in the cytoplasmic membrane, a selectively permeable membrane, to enter into the cell, nutrients must cross the other layer of cell.

- **Types of transport system**
   - Diffusion across lipid bilayer
   - Passive transport
   - Active transport

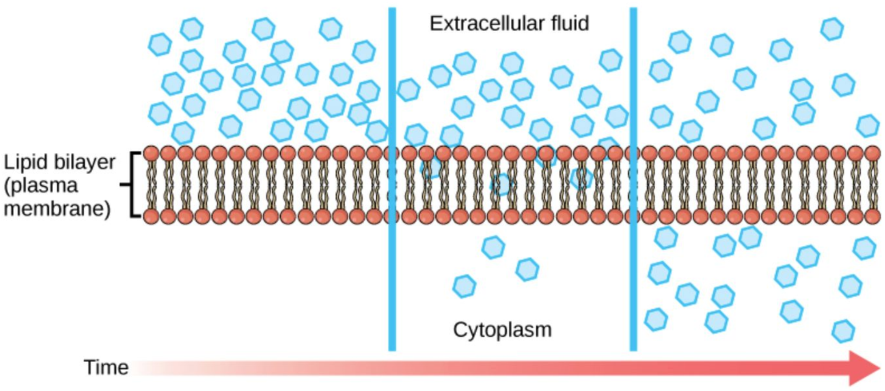
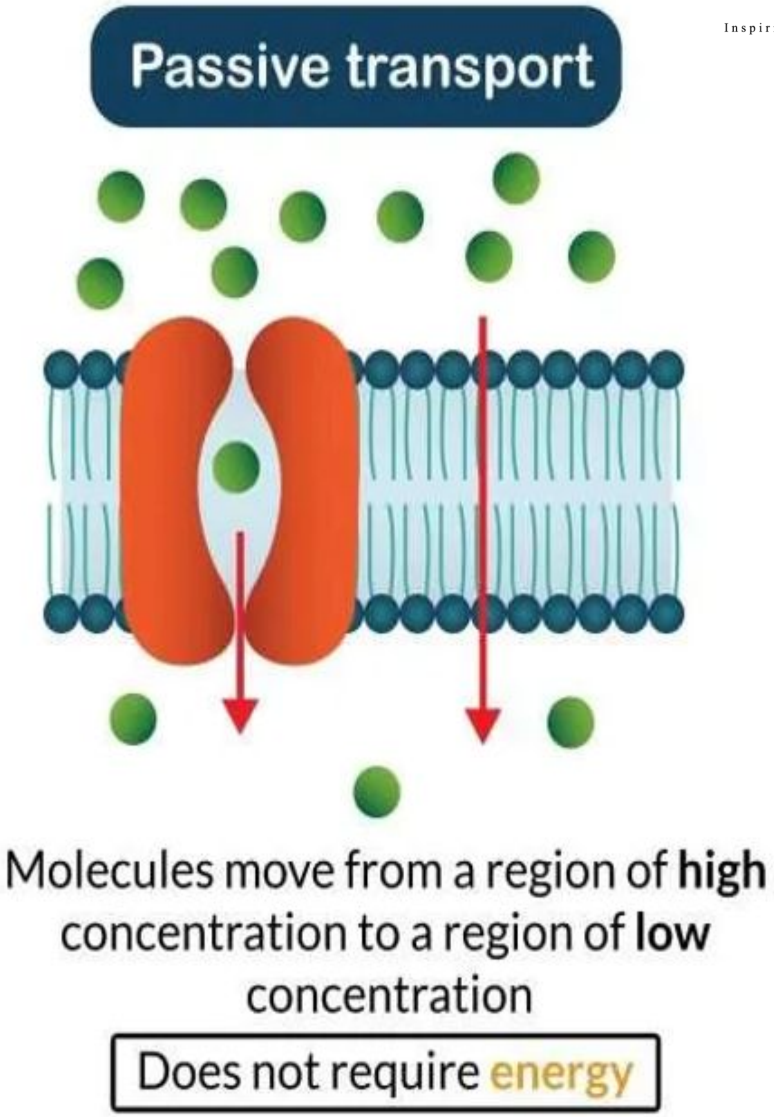


Image credit: OpenStax Biology, modified from original work by Mariana Ruiz Villareal.

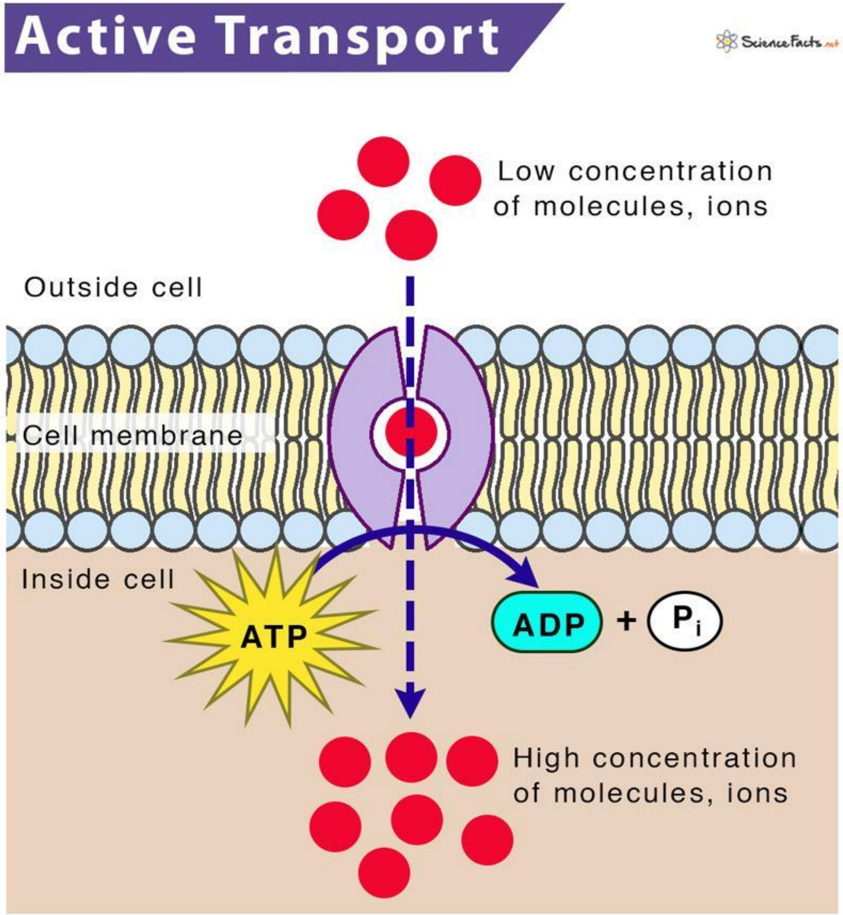
Passive Transport

- Flow of solutes through the interior of passive transport proteins down their concentration gradients (From high to low concentration).
- Passive transport proteins allow solutes to move both ways.
- Does not require any energy input.



Active Transport

- Movement of molecules from an area of lower concentration to the area of higher concentration (against concentration gradient).
- Transport protein must be activated.
- ATP gives up phosphate to activate transport protein.
- Binding of phosphate changes transport protein shape and affinity for solute.
- The other side opens, solute is released
- Removal of phosphate
- Protein goes back to its original state



Requires energy

How Cells Release Stored Energy

Cellular Respiration

- Pathway that breaks down an organic molecule to form ATP.
- In this process, organisms take molecules broken down from food and release the chemical energy stored in the chemical bonds of those molecules.
- Example: Cells convert sugar into energy

Aim:

- To create ATP to power cellular reactions, cells require fuel and an electron acceptor which drives the chemical process of turning energy into a usable form.
- The energy that is released from chemical bonds during cellular respiration is stored in molecules of ATP

ATP is called the energy currency of all biochemical processes!

What types of organisms undergo cellular respiration?

Animals, plants, fungi, algae and other protists (also in prokaryotes in cytoplasm)

What types of molecules are broken down?

- Any food (organic) molecule, or nutrient, including carbohydrates, fats/lipids and proteins can be processed and broken down to produce ATP

Stages of Cellular Respiration/ Aerobic Respiration

1. Glycolysis
2. Pre-Krebs Cycle (Pyruvate to Acetyl Co-A)
3. Citric Acid Cycle/TCA cycle/Krebs Cycle
4. Electron Transport Chain

$$C_6H_{12}O_6 + 6O_2 \xrightarrow{\text{Cellular respiration}} 6CO_2 + 6H_2O + ATP$$

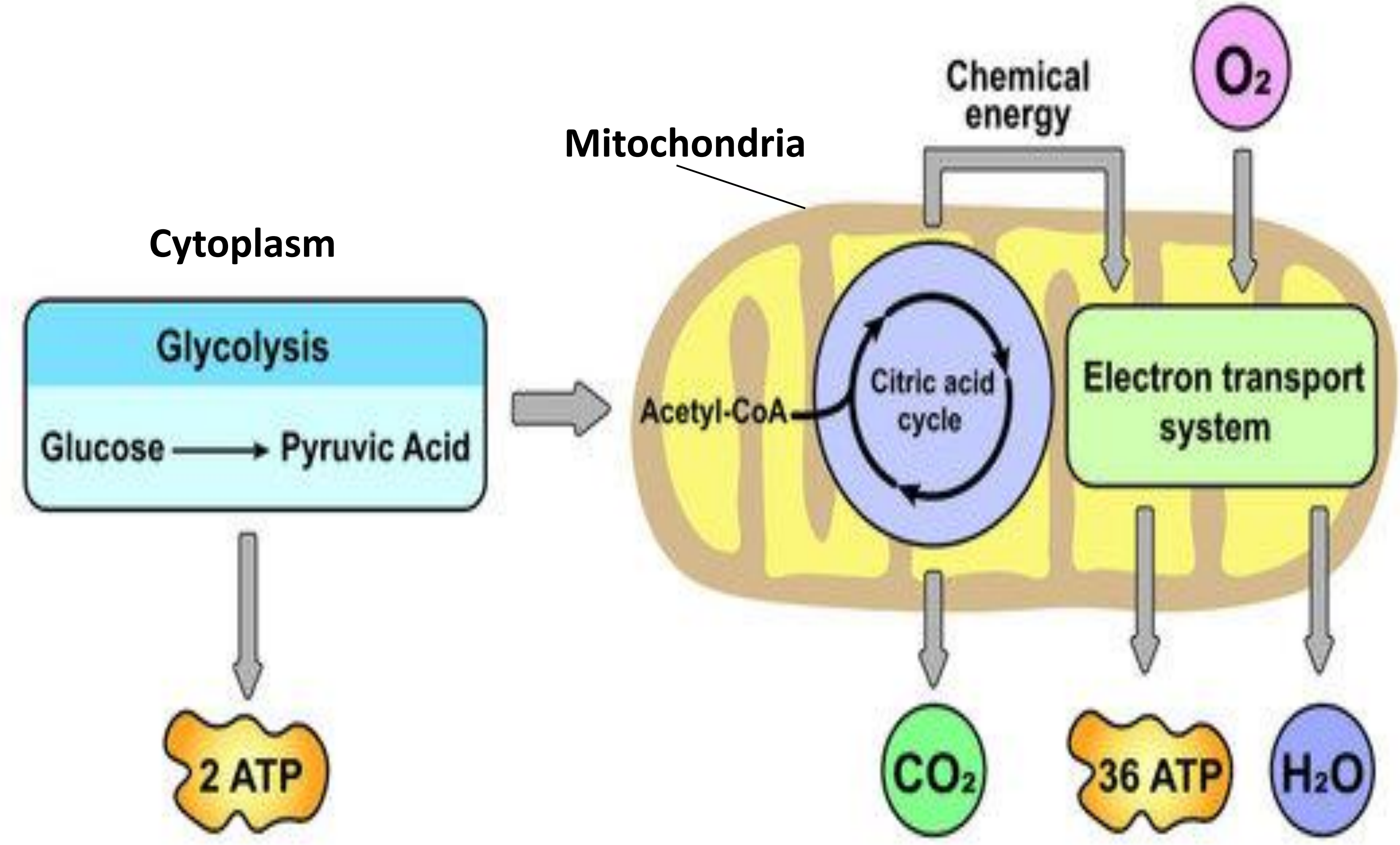
Simple equation of cellular respiration

Cellular Respiration/ Aerobic Respiration

- Overall, cellular respiration is a process that is **aerobic.**
- Aerobic means that it requires the presence of oxygen.
- One step: **Glycolysis**, of cellular respiration do not require the presence of oxygen and is therefore an **anaerobic step.** This is the only stage that is **completed in cytoplasm**.
- **Rest of the stages** are completed **in mitochondria (powerhouse: produces majority of cell's ATP)**.

- Energy carriers found within this process: **ATP**
- Electron carriers found within the process: **NADH, $FADH_2$**

Aerobic respiration



Glycolysis

- First stage of aerobic respiration.
- Set of reactions that produce ATP by converting one glucose to two pyruvates.
- All reactions are mediated by enzymes.

- Anaerobic step in the cellular respiration pathway therefore it **DOES NOT require oxygen**

- **Location:** **Cytoplasm** (For both prokaryotes & eukaryotes)
- **Product:** 2 Pyruvate, net yield of two ATP and two NADH.

- Pyruvate moves to mitochondria

Figure **Overview of glycolysis.**

Glycolysis converts one molecule of glucose to two molecules of pyruvate, for a net yield of two ATP and two NADH. An animal cell is shown, but the pathway occurs in the cytoplasm of all cells, prokaryotic and eukaryotic.

Glucose		**2 Pyruvate**
-C-C-C-C-C-C-	$\longrightarrow$	-C-C-C- -C-C-C-
(six carbons)		(three carbons)

Pre-Krebs Cycle (Pyruvate to Acetyl-CoA)

- Before **a pyruvate** enters the Kreb's Cycle, it combines with an enzyme called Coenzyme A (CoA).

- This reaction produces **one molecule of Acetyl CoA from one pyruvate**.

- **Acetyl CoA** is a molecule produced

by almost all nutrients (carbohydrate, protein, lipid) before entering the Kreb's cycle.

- **Location:** mitochondrial matrix (eukaryotes), cytoplasm (prokaryotes)
- **Product:** Acetyl CoA; CO_2 released, NADH produced.

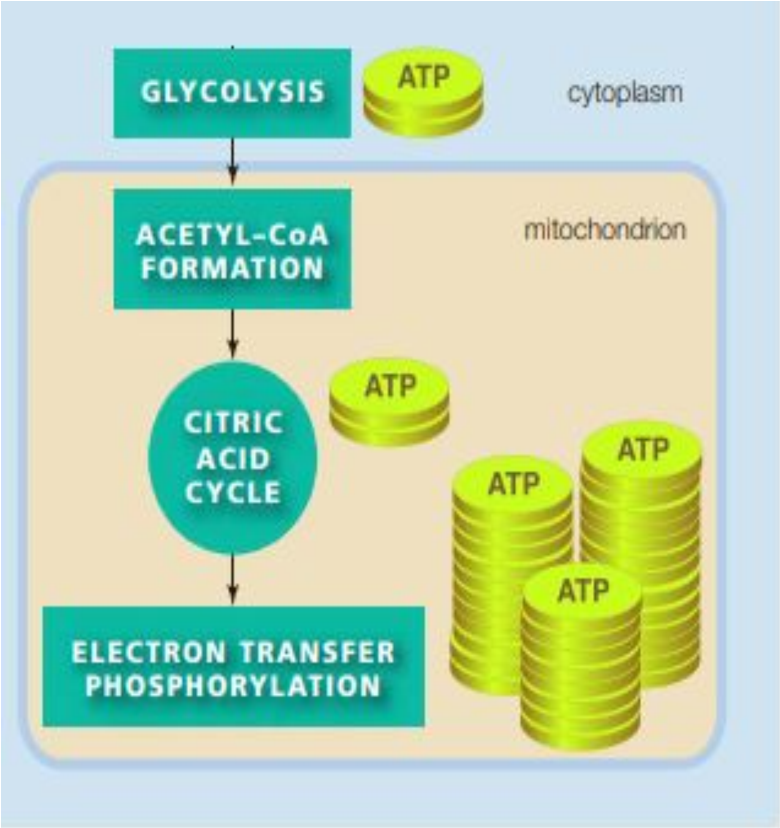


Fig: Pathway to Citric Acid Cycle

Krebs Cycle

- Named after Hans Krebs.

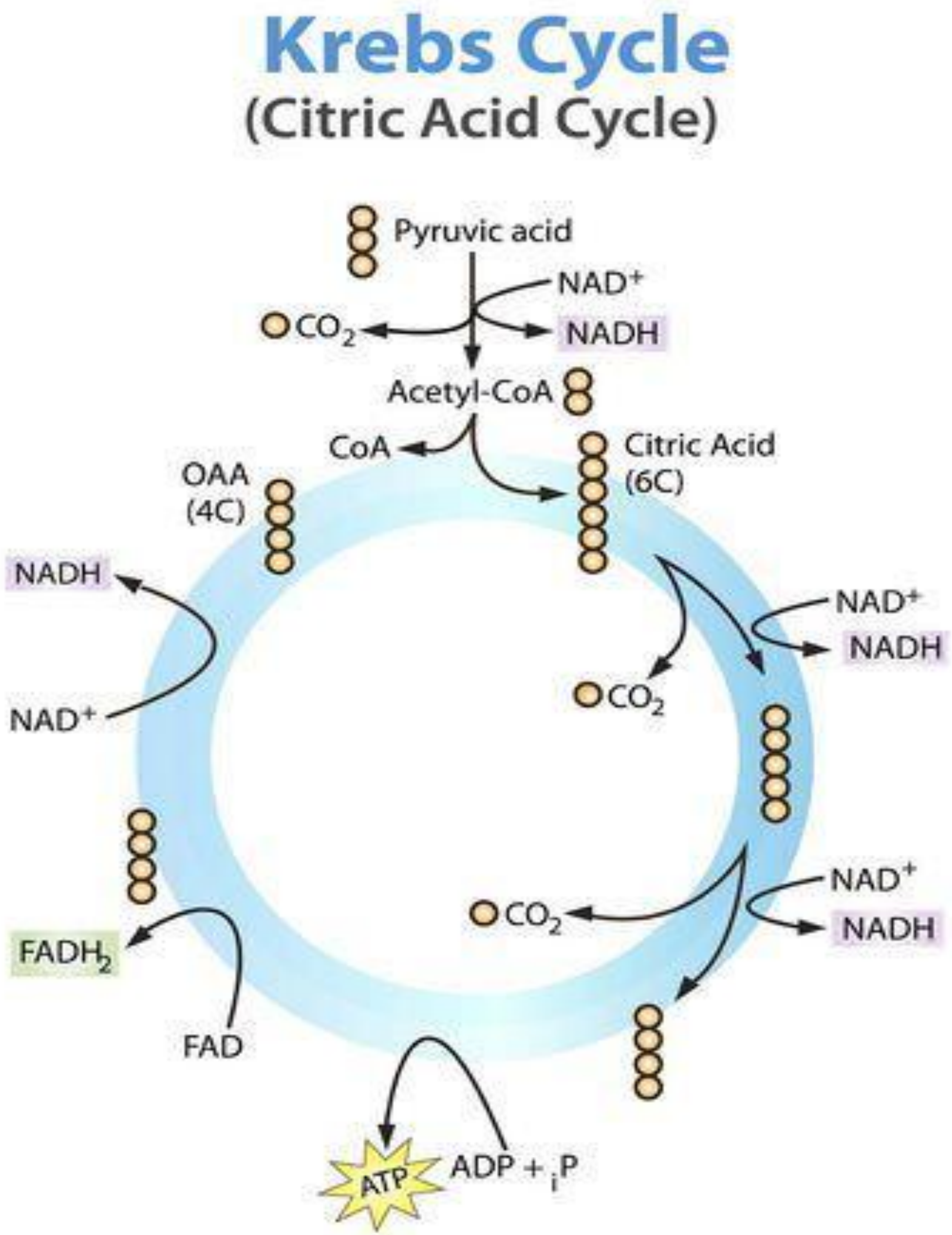
- Requires **oxygen (aerobic).**
- An Acetyl CoA (formed from Pyruvate) combines with a four-carbon molecule to make one molecule of citric acid: starting molecule of Kreb's cycle.
- Citric acid is broken down in several steps providing the energy to make NADH, $FADH_2$, ATP.

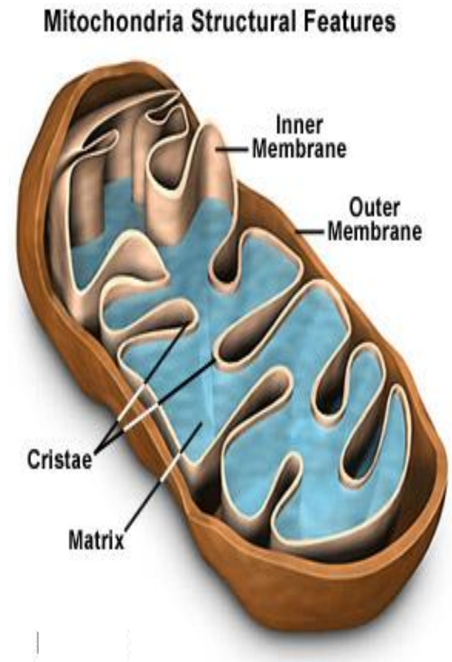
- **Cyclical series** of oxidation reactions that give off CO_2 and produce one ATP per cycle.


Hans Adolf Krebs (1900-1981)

- Turns twice per glucose molecule (produces 1 ATP per turn).
- Produces (2 X 1 ATP) = 2 ATP molecules from 1 glucose molecule.

- **Location: Mitochondrial matrix (eukaryotes), Cytoplasm (prokaryotes)**
- **Product:** NADH, $FADH_2$, ATP; CO_2 released.





Product summary/ glucose molecule

- 2 ATP $\longrightarrow$ Usable energy
- NADH $\longrightarrow$ Goes to ETC
- $FADH_2$ $\longrightarrow$ Goes to ETC
- CO_2 $\longrightarrow$ By product

Electron Transport Chain

- The ETC is a series of proteins located in the inner mitochondrial membrane.
- It accepts high energy electrons from the NADH and $FADH_2$ provided by the previous steps
- As the electrons move down the chain, energy is released. This energy is used to move H^+ (proton) out of matrix which creates a concentration gradient.
- These H^+ flows down the concentration gradient, into matrix through ATP synthase to form ATP.

- **Oxygen** is used as the final electron acceptor at the end of the ETC.
- Oxygen receives electrons and hydrogen ions (H^+) and produces H_2O.
- Location: **Inner mitochondrial membrane (Eukaryotes)**

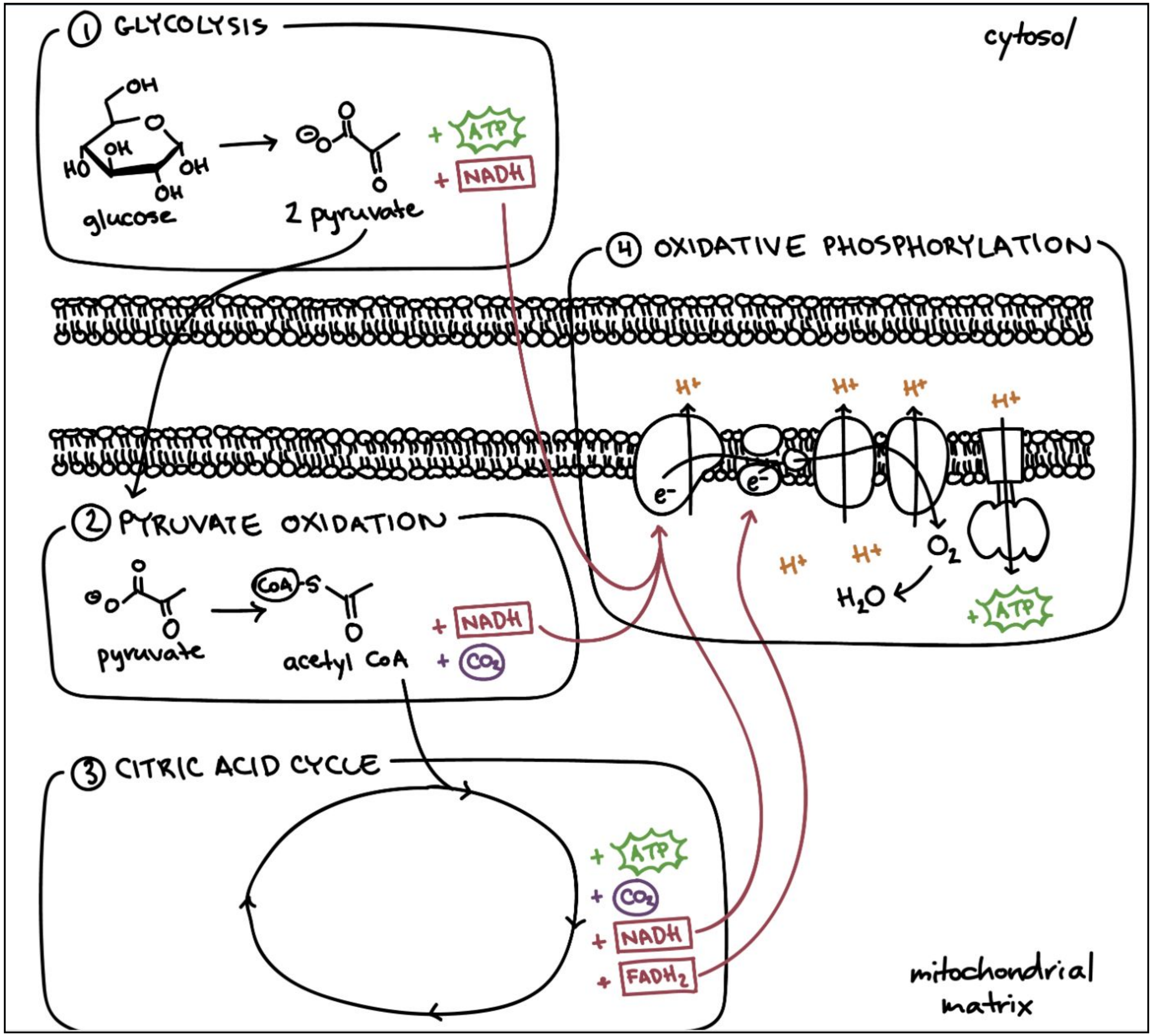
  Cytoplasmic membrane (Prokaryotes)

- The mitochondria is considered to be the "powerhouse" of the cell because it produces the majority of a cell's ATP

Electron Transport Chain

ETC Product Summary

- **34 ATP** → Usable energy
- **H_2O** → By product



Courtesy of: Khan Academy

Cellular Respiration ATP Tally (for 1 glucose mol.)

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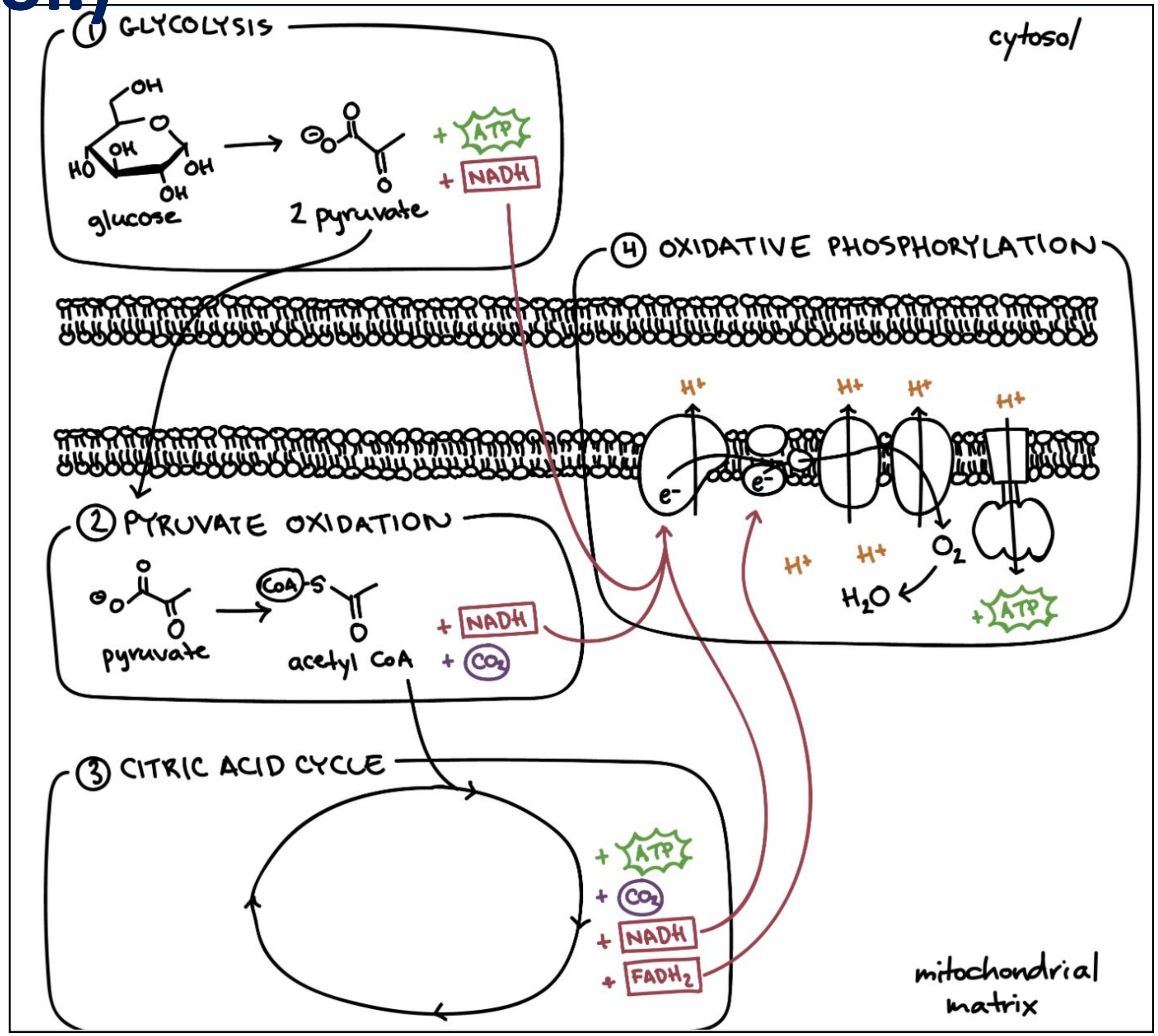
1. Glycolysis = 2 ATP
2. Krebs Cycle = 2 ATP
3. ETC = 32 to 34 ATP

Grand Total = 36 – 38 ATP



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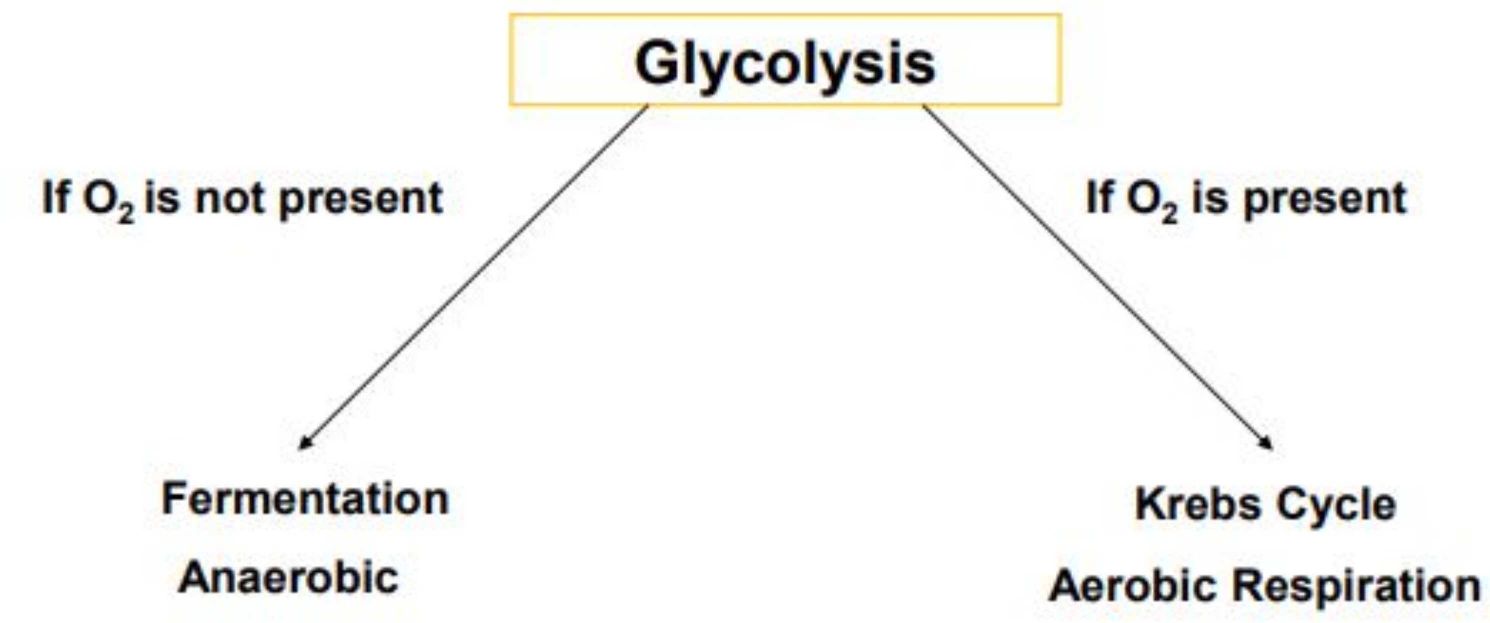
What happens after glycolysis if oxygen is not present?



Fermentation

- Glucose-breakdown pathways, that make ATP without the use of oxygen or electron transfer chains.
- If **oxygen is not present**, the products of glycolysis (pyruvate and NADH) will enter an alternative process called fermentation.

- Like aerobic respiration, fermentation **begins with** the **glycolysis** pathway (anaerobic step).
- Uses **pyruvate/ other molecules, as a final electron acceptor** (instead of O_2)
- Location: **Cytoplasm**

- Two types of fermentation:
  - **Lactic Acid Fermentation** = Humans (muscle cells)
  - **Alcoholic Fermentation** = Yeasts (bread making)

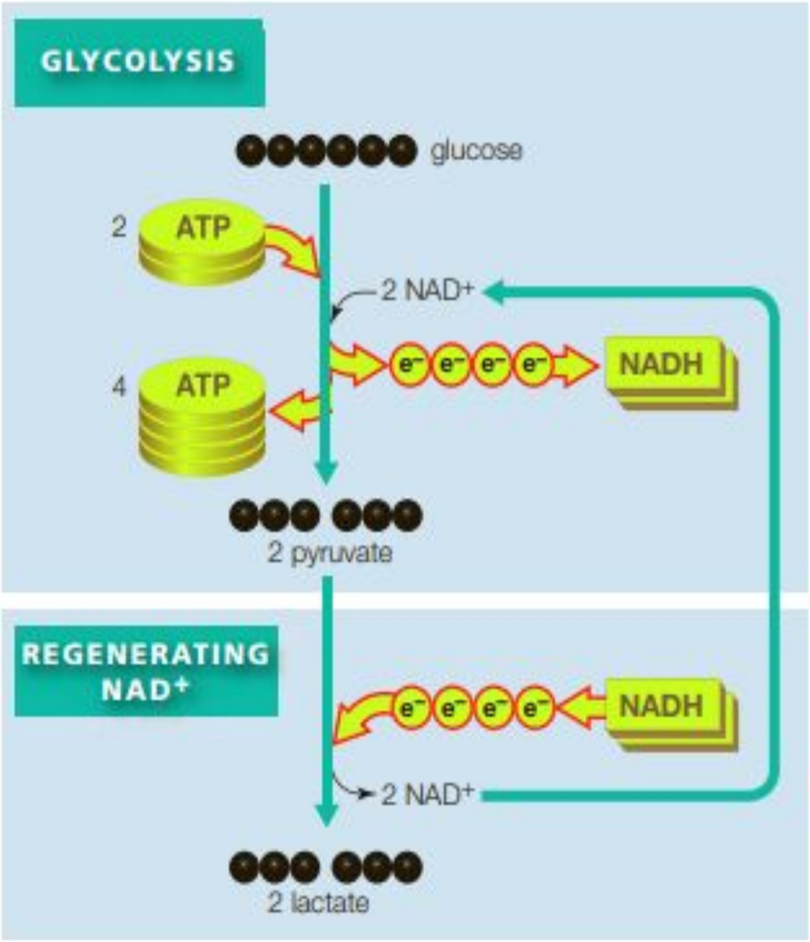
Examples of Fermentation

Lactic Acid fermentation

After doing heavy exercise, the body cannot supply oxygen into the cells in the appropriate amount, then **muscles** switch to fermentation (anaerobic process) to produce energy by producing lactic acid.

The result of lactic acid fermentation in muscles and body parts leads to stiffness or cramps.

- **Electron acceptor: Pyruvate**
- **Location: Cytoplasm**
- **Product: Lactic acid, ATP (generated only in glycolysis)**



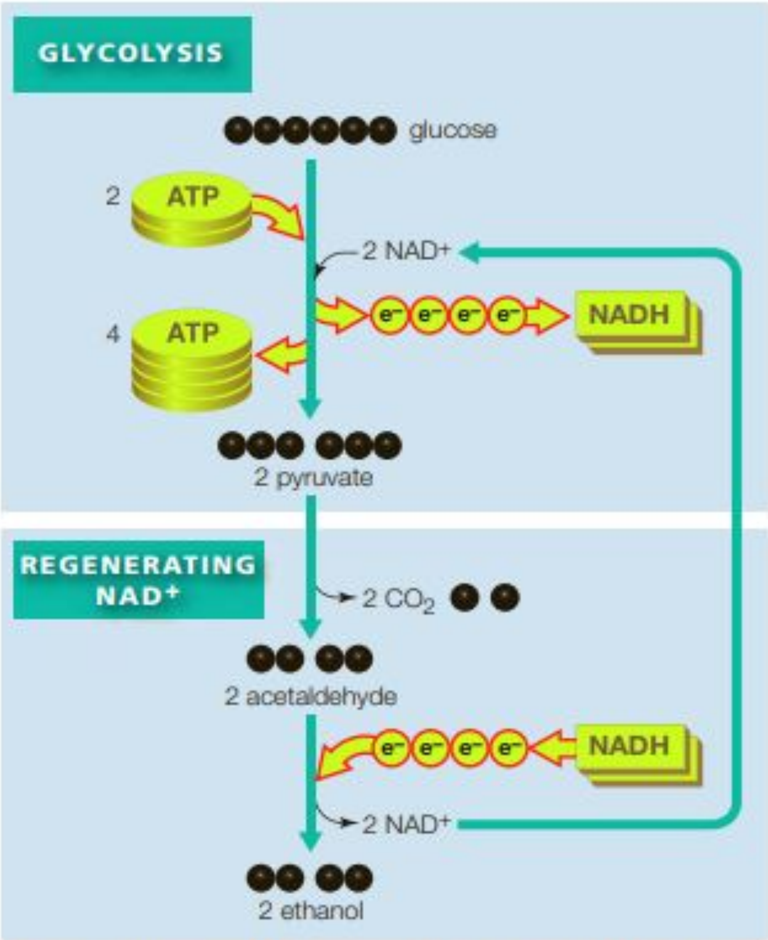
A Lactate fermentation begins with glycolysis, and the final steps regenerate NAD^+. The net yield of these reactions is two ATP per molecule of glucose (from glycolysis).

Examples of Fermentation

Alcoholic Fermentation

Saccharomyces cerevisiae, also known as brewer's or baker's yeast, converts sugars and starches into alcohol and carbon dioxide during the fermentation process.

- **Electron acceptor: Acetaldehyde**
- **Location: Cytoplasm**
- **Product: Ethanol, ATP (generated only in glycolysis)**



A Alcoholic fermentation begins with glycolysis, and the final steps regenerate NAD^+. The net yield of these reactions is two ATP per molecule of glucose (from glycolysis).

Aerobic Respiration	Fermentation
Oxygen is required to derive energy.	Oxygen is not required in this process.
Site of occurrence : Cytoplasm & Mitochondria.	Site of occurrence: Cytoplasm.
End products are CO_2 & water.	End products are lactic acid; ethanol, CO_2.
Involvement of electron transport chain & kreb's cycle.	No electron transport chain & kreb's cycle.
Final electron acceptor: Molecular oxygen.	Final electron acceptor: Organic molecule (e.g Pyruvate).
About 36 molecules of ATP are produced.	Only 2 molecules of ATP are generated.
Mainly occurs in higher organisms.	Mainly occurs in microorganisms.

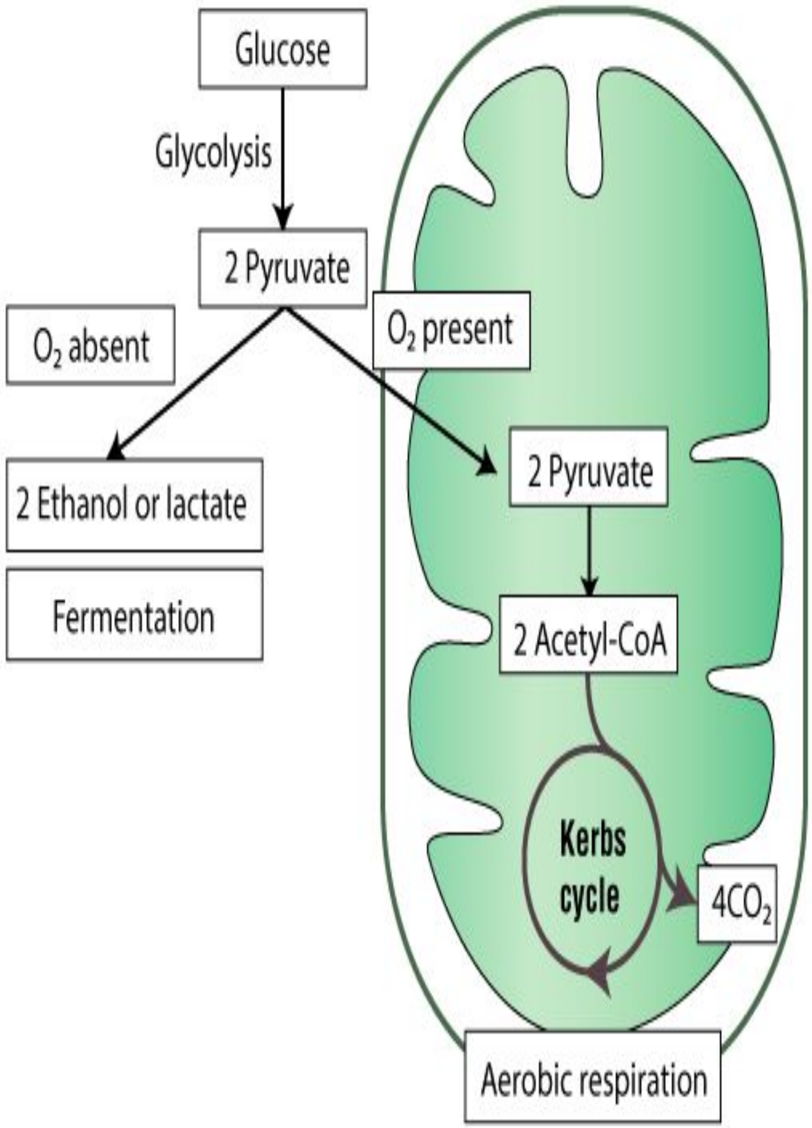
Advantages of Fermentation

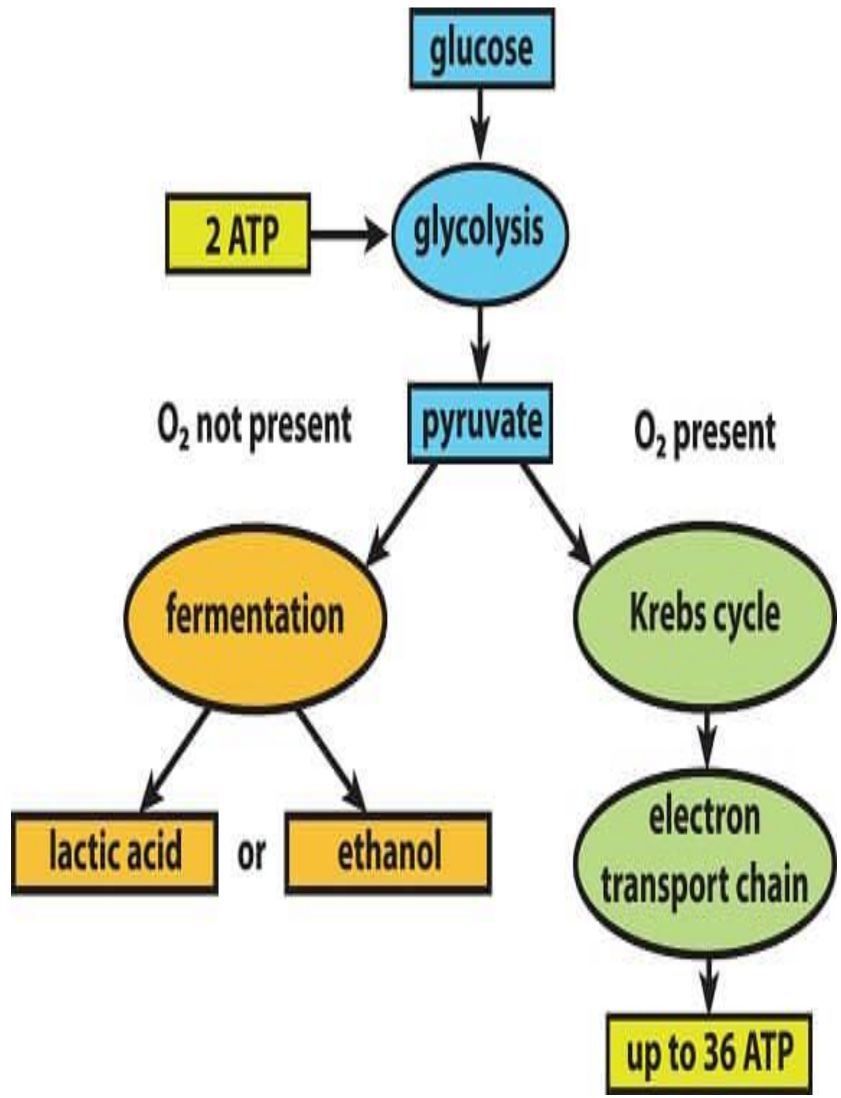
- **Increases habitat:** It lets organisms live in places where there is little or no oxygen. Such places include deep water, soil, and the digestive tracts of animals such as humans, some bacteria live in the human digestive tract.
- **Speed:** It produces ATP very quickly. For example, it lets muscle cells get the energy they need for short bursts of intense activity. Aerobic respiration, on the other hand, produces ATP more slowly.

Aerobic Respiration vs Fermentation

- Aerobic respiration produces much more ATP than fermentation.
- Fermentation occurs more quickly than aerobic respiration.

Overview of the Process





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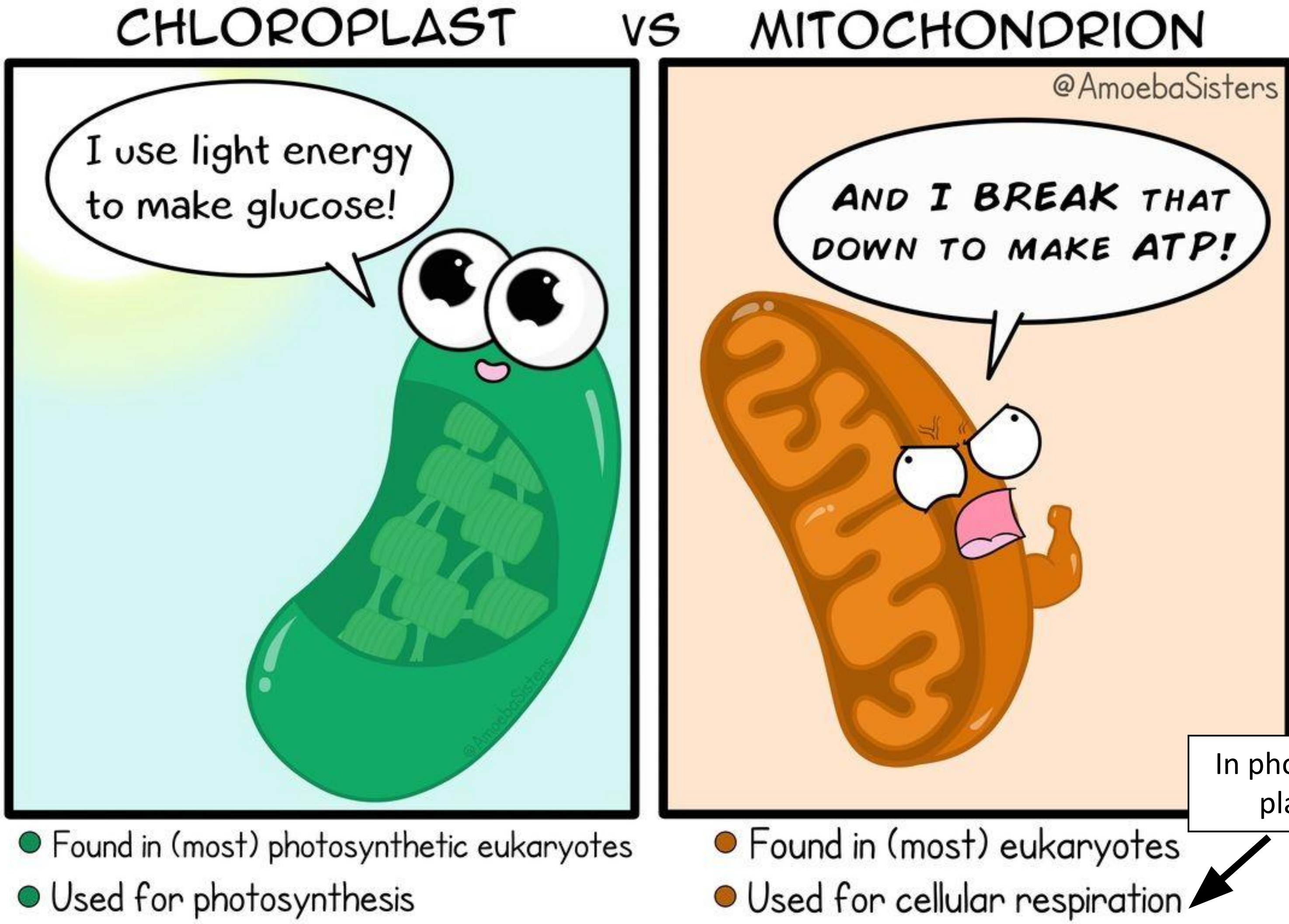

In photosynthetic plants too!

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