CELLULAR RESPIRATION

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What is Cellular Respiration?

- The process in which organisms take molecules broken down from food and release the chemical energy stored in the chemical bonds of those molecules.
- It’s important to remember that food is not the direct source of energy.

Cellular Respiration: An Overview

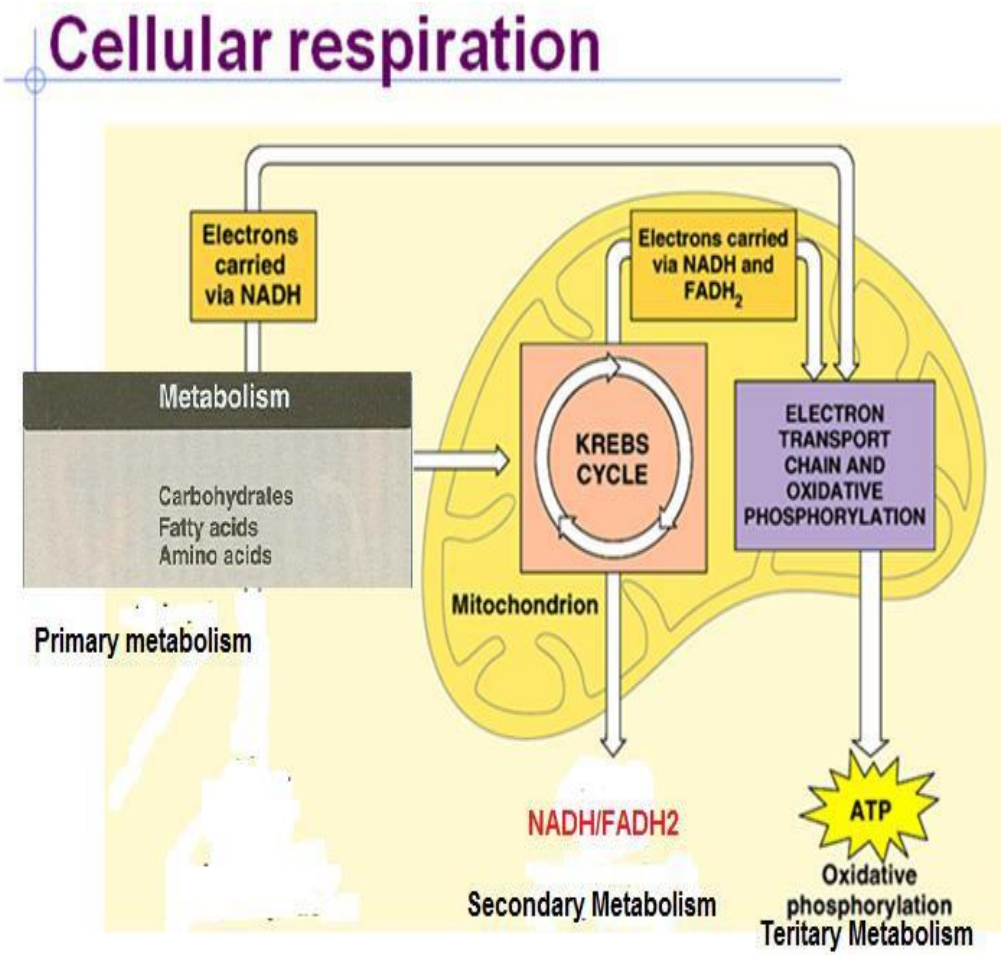
- **Living things get most of the energy they need from glucose.**

- **Cellular Respiration:**

- The process that **releases energy** by **breaking down glucose and other food molecules** in the **presence of oxygen**.

- The energy that is released from chemical bonds during cellular respiration is stored in molecules of ATP.

Stages of oxidation of food stuffs



First stage:

Digestion in the GIT converts the macro molecules into small units. (carbohydrates into glucose, lipids into fatty acids, proteins into amino acids).
This is called primary metabolism.

Second stage: These products are absorbed in mitochondrial citric acid cycle to generate reducing equivalents NADH or FADH2.
This is called secondary or intermediary metabolism.

Third stage: These reducing equivalents enter into the electron transport chain or respiratory chain where energy is released (ATP).
This is tertiary metabolism or internal or cellular respiration.

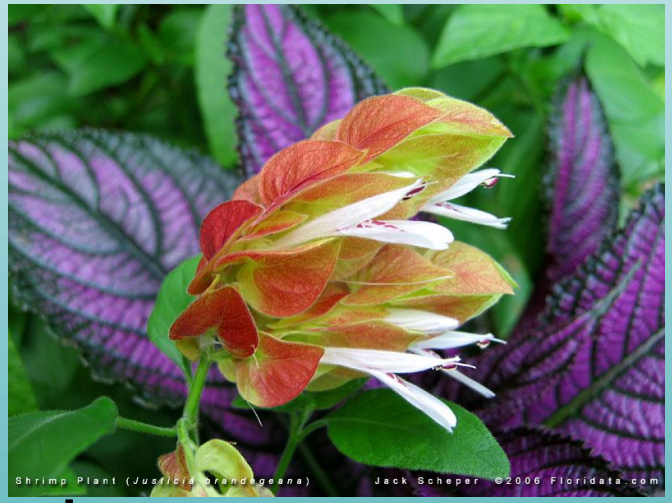
The energy (ATP) is then used for body synthetic purpose.

What types of organisms undergo cellular respiration?

- While only autotrophs undergo photosynthesis both

Heterotrophs

AND



Autotrophs

Undergo cellular respiration

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 as a source of energy to produce ATP.

What will the ATP be used for?

- ATP will release energy for cellular metabolic processes.
- Examples:
  1) Active transport of molecules across the cell membrane.
  2) Protein synthesis
  3) Muscle contractions

Cellular Respiration Simple Equation

Nutrients + Oxygen → Water + Energy (ATP) + Carbon Dioxide

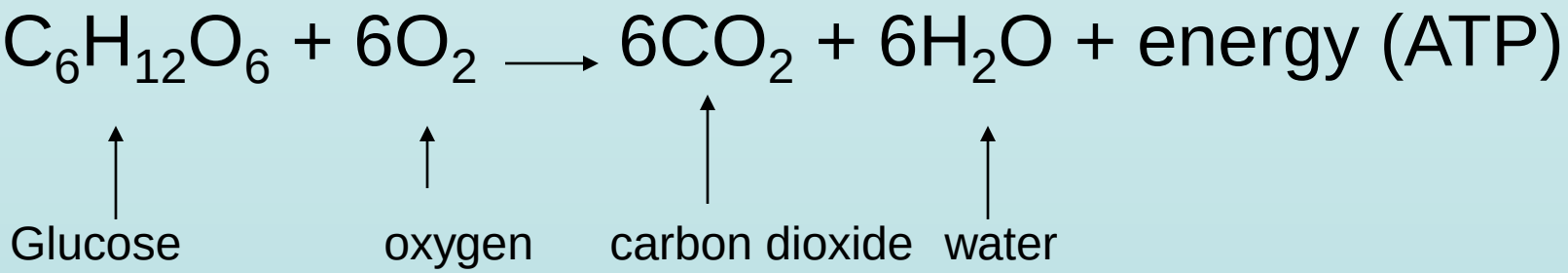
Photosynthesis Simple Equation

Water + Carbon Dioxide + Energy (sunlight) → Nutrients + Oxygen

Cellular Respiration and Photosynthesis

- Notice that the cellular respiration equation is the breakdown of those molecules made through photosynthesis and that it also uses the waste products of photosynthesis.
- Notice that photosynthesis uses those products made by cellular respiration.
- This is representative of a cycle.

The Cellular Respiration Equation



Biochemical Pathway

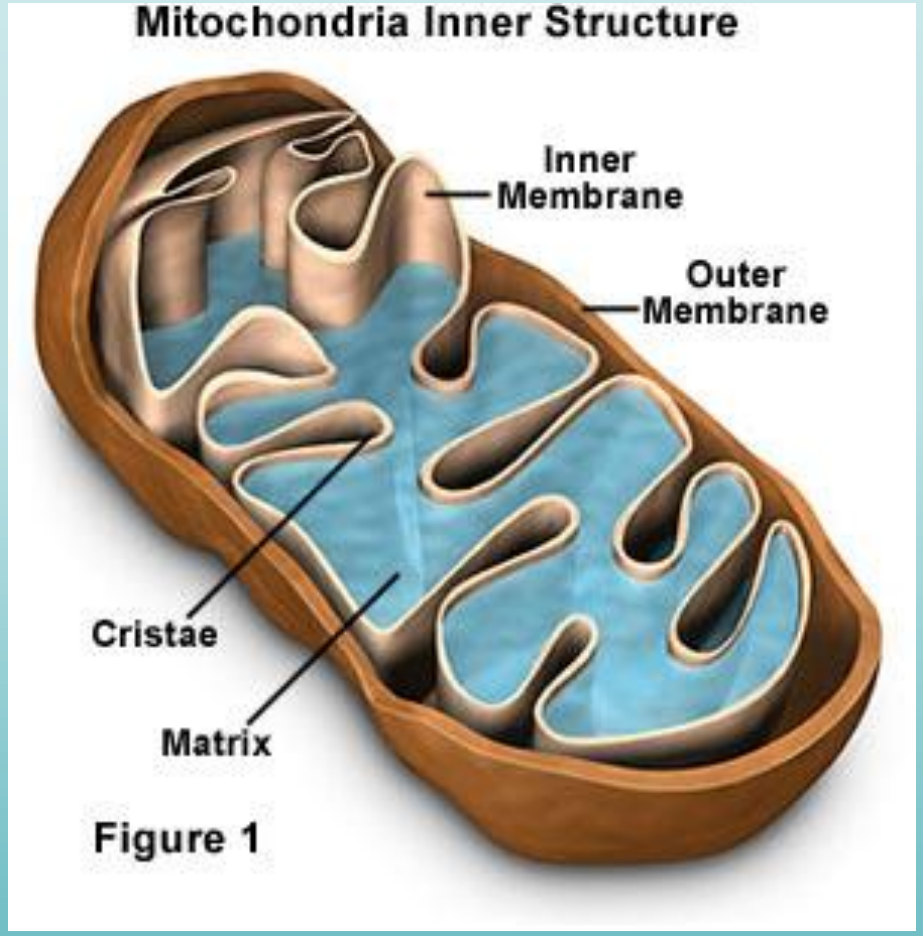
- Cellular Respiration is a biochemical pathway just like photosynthesis in which each step (chemical reaction) of the process is dependent on the products of the previous step.
- The cellular respiration equation represents many steps that have taken place.

- Overall, cellular respiration is a process that is **aerobic**. Aerobic means that it requires the presence of oxygen.
- Some steps within the process of cellular respiration do not require the presence of oxygen and are therefore **anaerobic.**

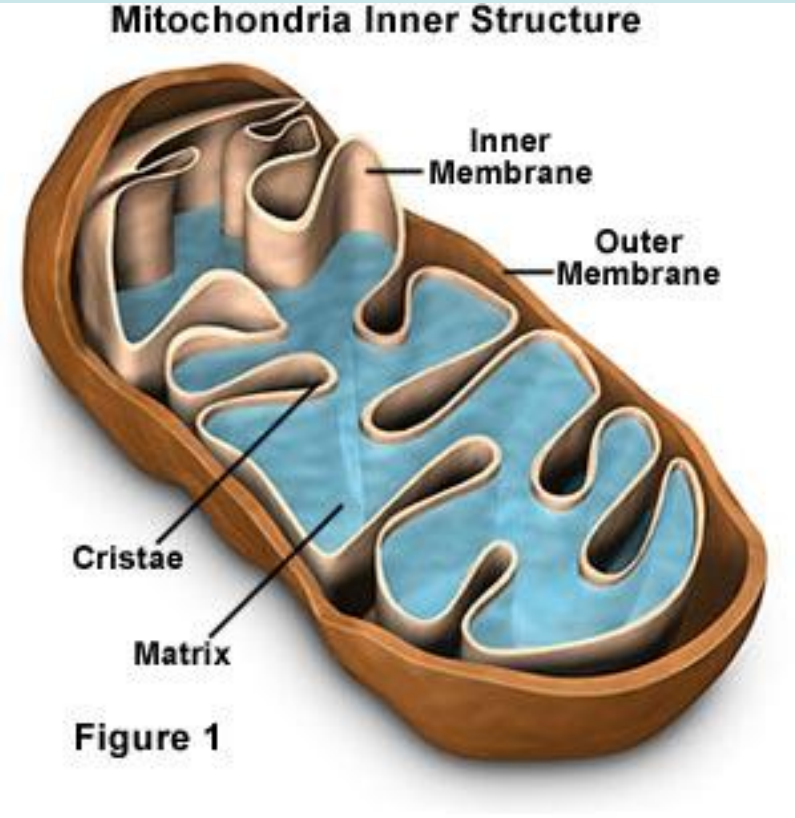
Where does cellular respiration occur?

- Cellular respiration takes place in the mitochondria of the eukaryotic cell.
- Recall that the mitochondria is considered to be the “powerhouse” of the cell because it produces the majority of a cell’s ATP.

Label the Parts of the Mitochondria



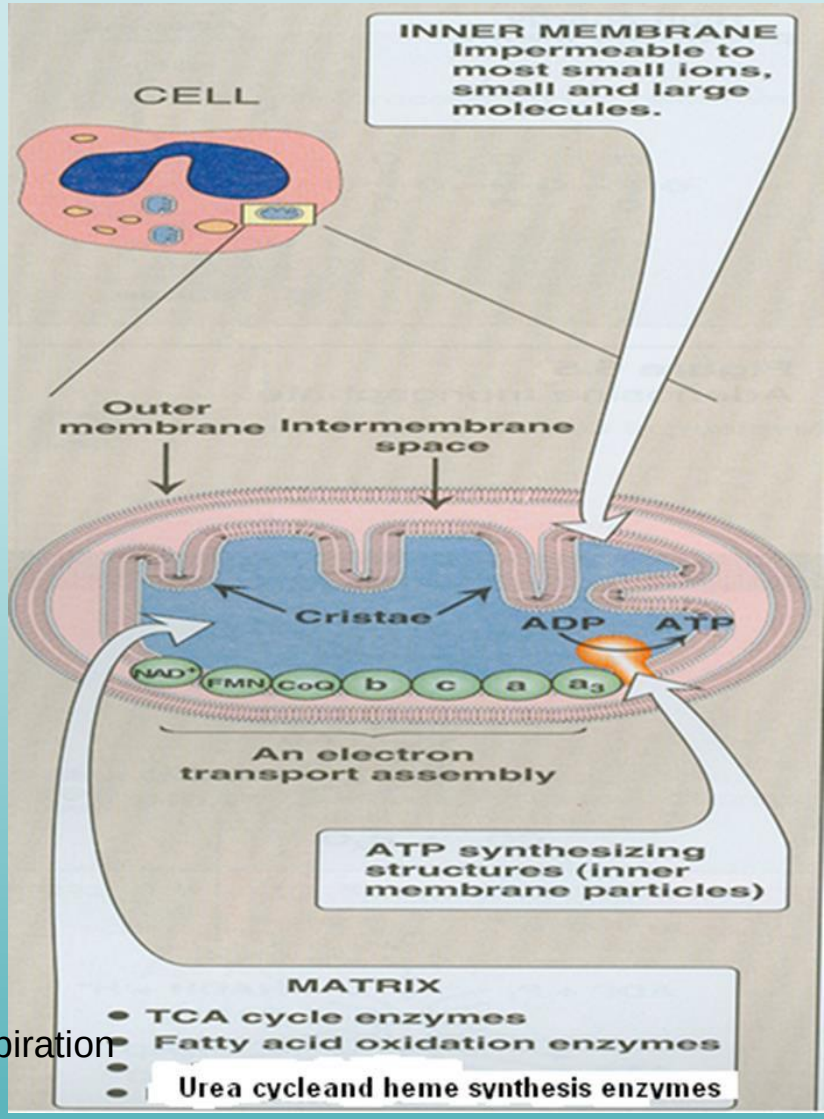
- Many similarities exist between the chloroplast and the mitochondria
- Mitochondria has a double membrane
- Mitochondria have their own DNA and only come from preexisting mitochondria.



- Mitochondria have a smooth outer membrane
- Mitochondria have a folded inner-membrane called the cristae. A folded inner membrane allows more surface area for chemical reactions to occur.
- Mitochondria have a center called the matrix.

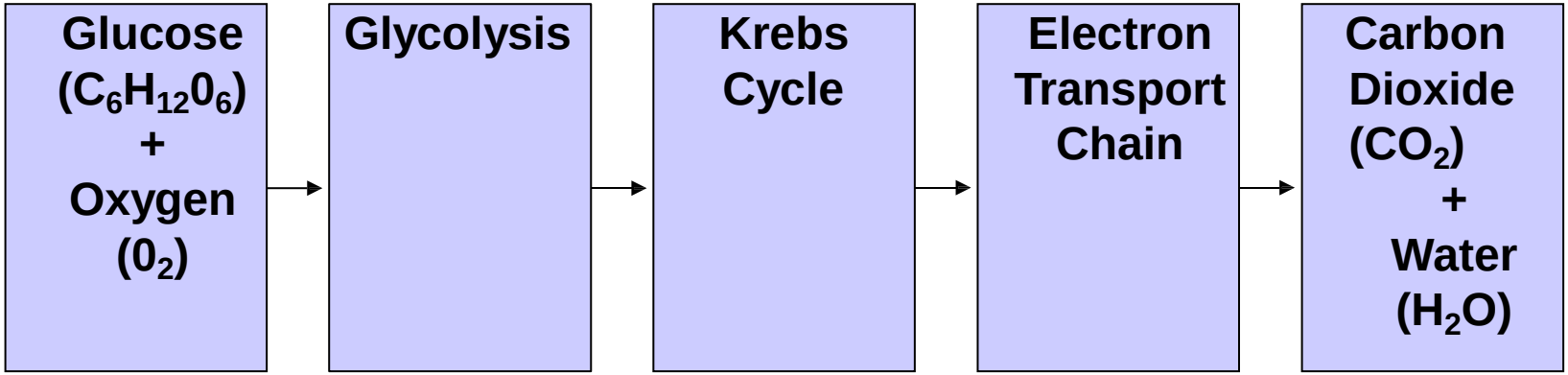
The “Mighty” Mitochondria

- The mitochondria is the organelle where the final stages of cellular respiration occurs.
  - ***Citric acid Cycle***
  - ***Electron Transport Chain***
- Cells that use a lot of energy have high numbers of mitochondria.
  - ***Example: Muscle cells in the heart!!***



Cellular Respiration in Detail

Cellular Respiration Flowchart



Glucose

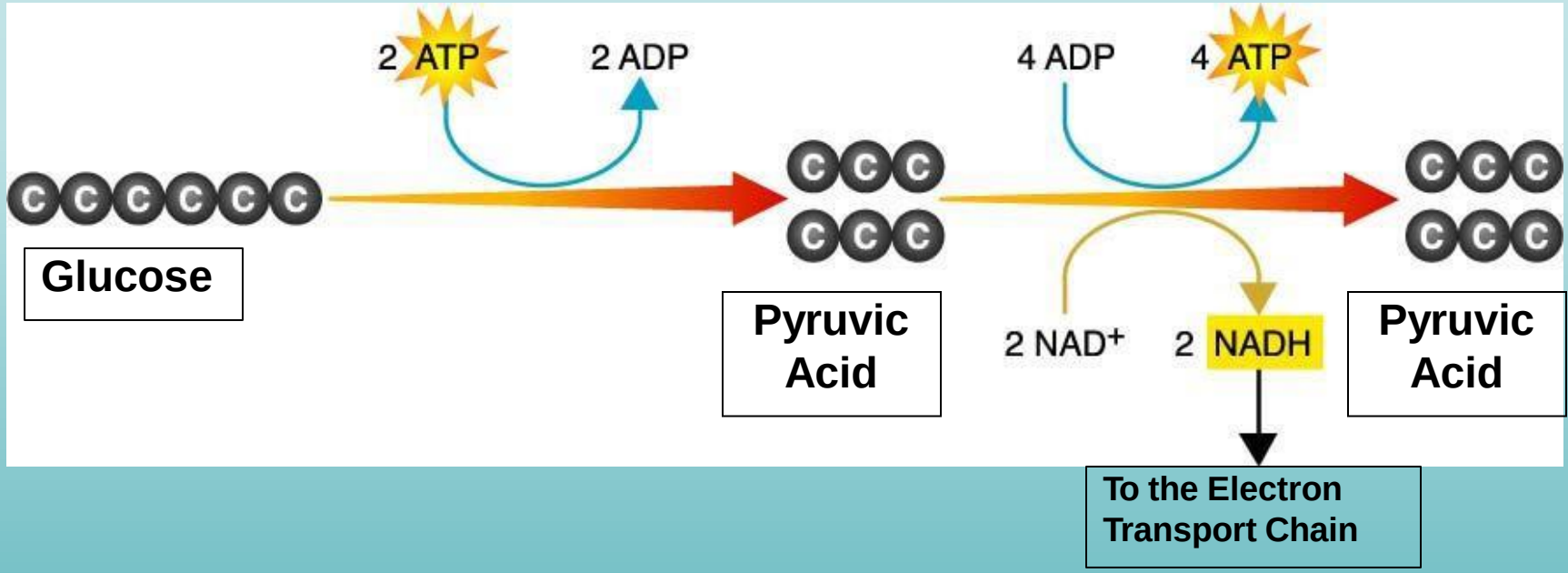
For the sake of simplicity *(as it is in photosynthesis)*, glucose is used as the example for cellular respiration. Remember that many different types of organic molecules are broken down through cellular respiration.

Cellular Respiration

Cellular respiration breaks down into these major steps.

1. Glycolysis (anaerobic)
2. Krebs Cycle (aerobic)
3. Electron Transport Chain (aerobic)

Glycolysis


2 ATP
2 ADP
4 ADP
4 ATP
Glucose
Pyruvic Acid
Pyruvic Acid
2 NAD+
2 NADH
To the Electron Transport Chain

Energy Carriers Found in Cellular Respiration

- **ATP**
- **NADH (similar to NADPH in photosynthesis)**
  - **Nicotinamide adenine dinucleotide (NAD) + Hydrogen (H)**
- **$FADH_2$**

  - Flavin adenine dinucleotide

Glycolysis

- Glycolysis is an anaerobic step in the cellular respiration pathway therefore it *doesn't* require oxygen.
- Glycolysis takes place in the cytoplasm of the cell and is a series of reaction using enzymes.

Glycolysis

- Glycolysis is the splitting of a molecule of glucose.
- The products of glycolysis are broken down in the mitochondria to make more ATP

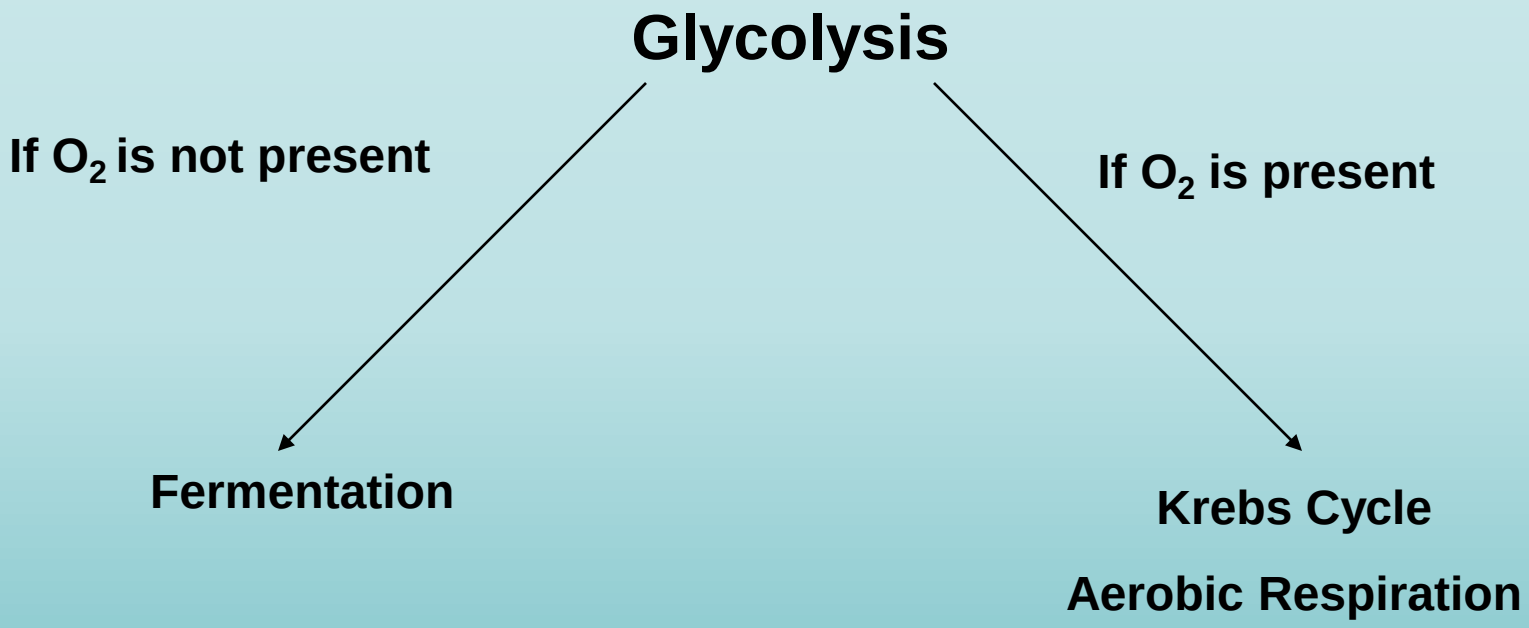
What are the products of glycolysis?

- When a molecule of glucose is split, pyruvic acid, NADH, and ATP are produced.
- Glycolysis makes 4 molecules of ATP but it takes 2 molecules of ATP for the reaction to occur. Therefore Glycolysis yields a net of 2 ATP molecules.

What moves on to the next Stage?

- Pyruvic acid is the main goal of glycolysis and these molecules will move on to the Krebs Cycle.
- Pyruvic Acid ⟶ Krebs Cycle
- NADH ⟶ ETC
- ATP ⟶ Usable Energy

After Glycolysis What Happens?



The Aerobic Pathway

Pre-Krebs Cycle (Acetyl- CoA)

- Before pyruvic acid enters the Krebs Cycle, it combines with an enzyme called Coenzyme A (CoA).
- This reaction produces a molecule of **Acetyl CoA**.
- Acetyl CoA is a molecule produced by almost all nutrients (carb., protein, lipids) before entering the Krebs cycle.

Pathway to the Krebs Cycle (citric acid cycle)

Glycolysis

↓

Pyruvic Acid

↓

Acetyl CoA

↓

Krebs Cycle

Krebs Cycle (Citric Acid Cycle)

- Named after Hans Krebs who won the Nobel Prize for the pathway he discovered in cellular respiration.

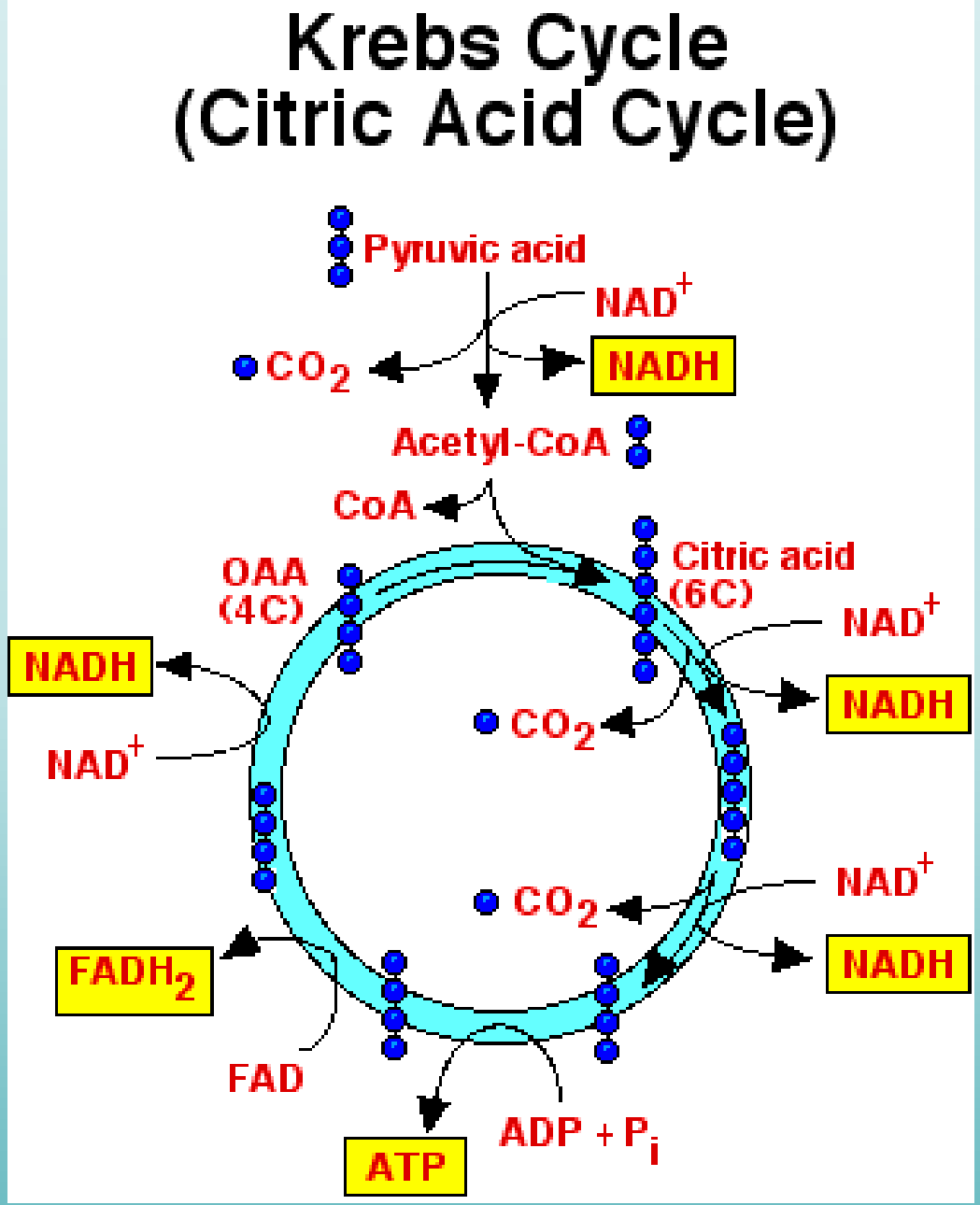
Krebs Cycle

- **Cyclical series of oxidation reactions that give off CO_2 and produce one ATP per cycle**
- **Requires Oxygen (Aerobic)**
- **Turns twice per glucose molecule (produces 1 ATP per turn).**
- **Produces two ATP**
- **Takes place in matrix of mitochondria**

Krebs Cycle

- Acetyl CoA (formed from Pyruvic Acid) combines with a four-carbon molecule to make a molecule of citric acid.
- Citric acid is broken down in several steps providing the energy to make NADH, $FADH_{2,}$, ATP.

Krebs Cycle (Citric Acid Cycle)



Krebs Cycle Reactant Summary

- Pyruvic Acid
- ADP
- NAD+ (Nicotinamide adenine dinucleotide)
- FAD+ (Flavin adenine dinucleotide)

Krebs Cycle Product Summary

- 2 ATP ⟶ Usable energy
- NADH ⟶ Goes to ETC
- $FADH_2$ ⟶ Goes to ETC
- CO_2 ⟶ Byproduct

The Electron Transport Chain

- The ETC is a series of proteins located in the mitochondrial membrane.
- It uses high energy electrons from the NADH and $FADH_2$ provided by the Krebs Cycle to move H+(protons) across the concentration gradient.
- These protons pass back down the concentration gradient through ATP synthase to form ATP. Very much like the ETC in the light reactions of photosynthesis.

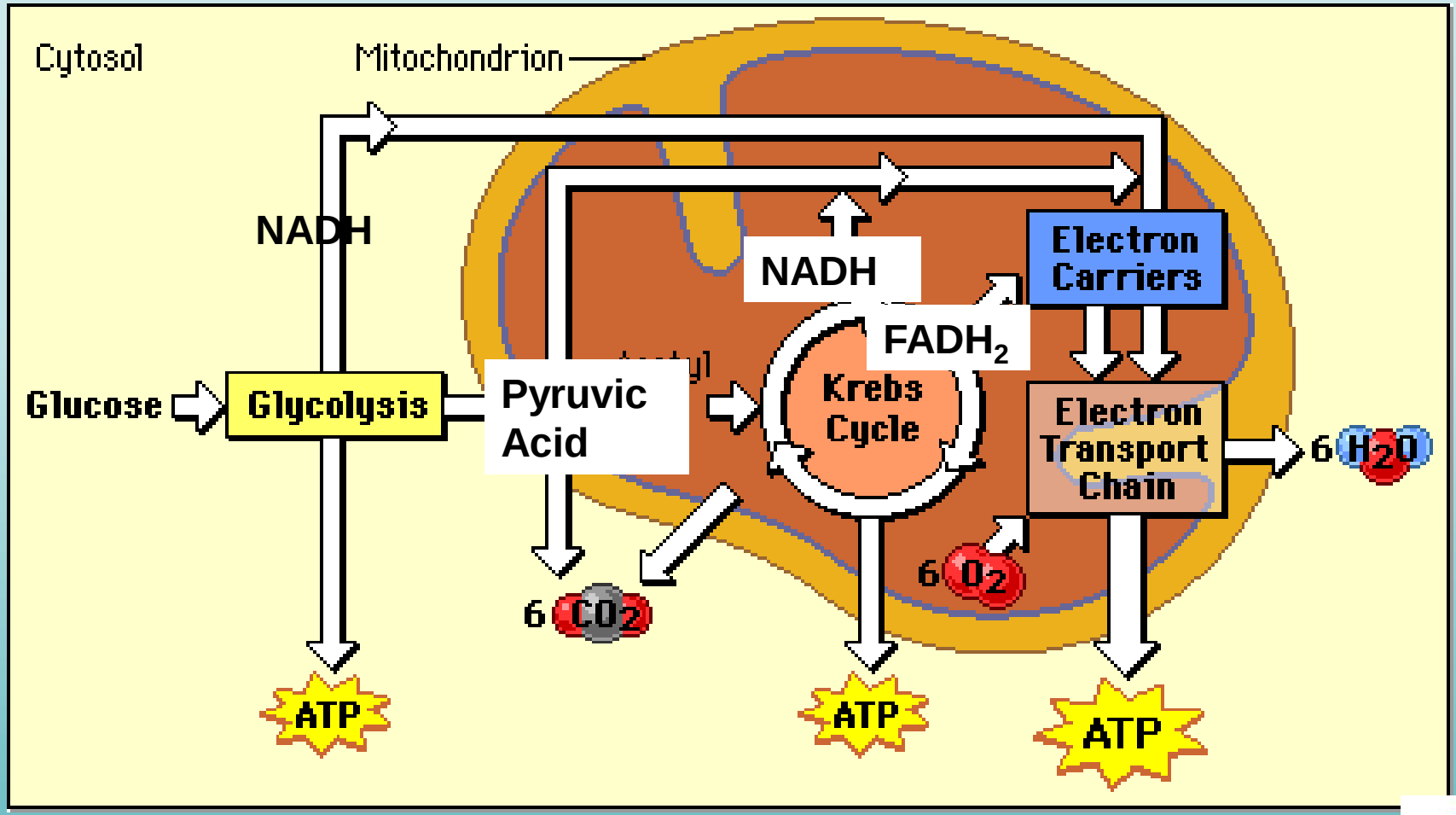
ETC

- Oxygen is used as the final electron acceptor at the end of the ETC.
- Oxygen receives electrons and H+(hydrogen ions) and produces a molecule of water.

ETC Product Summary

- 34 ATP → Usable energy
- H_2O → Byproduct

Overview of Aerobic Respiration



Cellular Respiration ATP Tally

1. Glycolysis – 2 ATP
2. Krebs Cycle – 2 ATP
3. ETC – up to 34 ATP

Grand Total = 36-38 ATP

Anaerobic Pathways
Fermentation

What happens to the products of glycolysis when O_2 isn't present?

Fermentation

- Breathing provides enough oxygen for your body to carry out normal activities.
- When you are conducting a high level of activity, breathing doesn't supply enough air for your cell's activities.

- If oxygen is not present, the products of glycolysis (pyruvic acid and NADH) will enter an alternative process called **fermentation.**
- Fermentation provides enough ATP and recycles NADH into NAD+ so that glycolysis may continue until more oxygen becomes available.

Where does fermentation occur?

- Cytosol of the cell

Two Types of Fermentation

- Lactic Acid
- Alcoholic

Lactic Acid Fermentation

- Occurs in muscle cells in the body.
- Lactic acid is a waste product of fermentation that will build up and cause your muscles to “burn” during hard exercise.

Lactic Acid Fermentation

- Lactic acid fermentation also occurs in some bacteria and molds.
- Waste products of the fermentation process give cheese different flavors.
- Yogurt is another product of lactic acid fermentation.

Alcoholic Fermentation

- Alcoholic fermentation is a process used by many yeasts and plants.
- Also uses the products of glycolysis (NADH and pyruvic acid) to provide enough NAD+ and ATP for glycolysis to continue.

Alcoholic Fermentation

- Alcoholic fermentation is used to make bread or dough rise and is also used for beer and wine.

Fermentation

- Bacteria that rely upon fermentation play a very important role in digestive systems of animals.
- They breakdown molecules by taking undigested material for their needs.
- Without these bacteria we'd be unable to fully digest food.

Questions

1. What is the real benefit of fermentation?
2. What is the cellular respiration equation?
3. What factor determines the pathway that pyruvic acid takes after leaving glycolysis?
4. What is the importance of cellular respiration to us?
5. Explain how cellular respiration complements photosynthesis.
6. What is the ultimate end product of cellular respiration?