CELLULAR RESPIRATION

GENERAL BIOLOGY 1

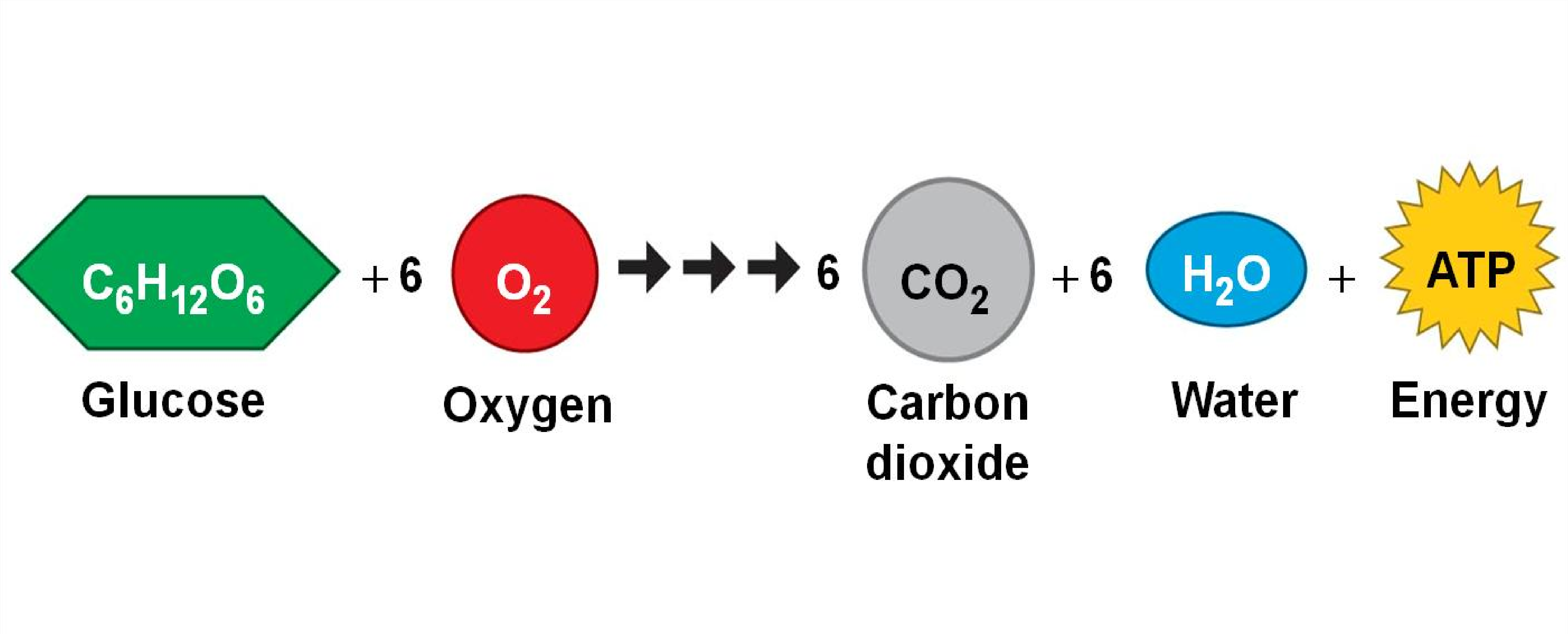
LEARNING COMPETENCIES

- Differentiate aerobic from anaerobic respiration
- The major features and sequence the chemical events of cellular respiration.
- Distinguish major features of glycolysis, Krebs cycle, electron transport system, and chemiosmosis.
- Describe reactions that produce and consume ATP
- Describe the role of oxygen in respiration and describe pathways of electron flow in the absence of oxygen

CELLULAR RESPIRATION

- Cells release energy in food by breaking chemical bonds in a chain of chemical reaction.
- Cellular Respiration is a ***catabolic reaction***, which breaks down food or organic substances to extract energy.
- Fats, proteins, and carbohydrates cannot be used directly as energy, it needs to be broken down chemically to generate molecules of **ATP**.
- It occurs in the presence of oxygen **(Aerobic)** and in the absence of oxygen **(Anaerobic).**

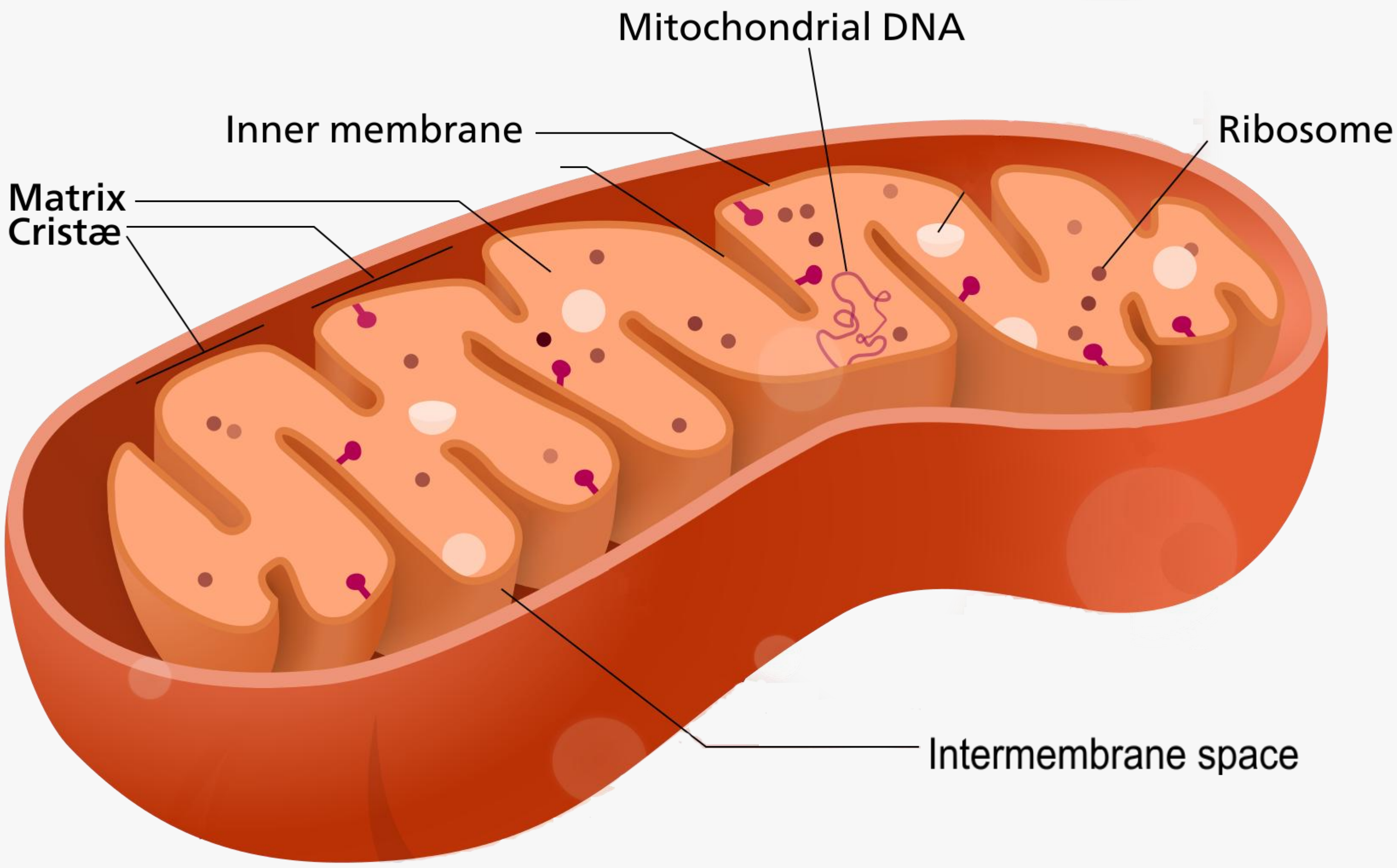
Chemical Equation



CELLULAR RESPIRATION

- In cellular respiration, the product of Photosynthesis (Glucose and Oxygen) are the reactants of Cellular Respiration, and the final product of Cellular Respiration are the reactants of the reactants of Photosynthesis (Carbon Dioxide and Water) additionally it also produces energy (ATP).
- Its process consists of three major stages: **Glycolysis, Kreb Cycle, and the Electron Transport Chain**
- It happens in the Cytoplasm, but majority of its process happens in the ***Mitochondria***.

MITOCHONDRIA



MITCHONDRIA

- Mitochondria have different parts:
  - ☐ **Outer Membrane** - contains proteins known as porins, which allow movement of ions into and out of the mitochondrion
  - ☐ **Matrix** - the area inside the inner membrane; contains ribosomes, enzymes and circular mitochondrial DNA necessary for mitochondria to function
  - ☐ **Inner Membrane** - contains enzymes essential for cell respiration; Less permeable; it is the site of the electron transport chain and location of ATP synthase (used in oxidative phosphorylation)
  - ☐ **Cristae** - which are folded section of the inner membrane, increase the surface area available for energy production via oxidative phosphorylation.

MITOCHONDRIA

STAGES OF CELLULAR RESPIRATION

STAGES OF CELLULAR RESPIRATION

GLYCOLYSIS, KREB CYCLE, AND OXIDATIVE PHOSPHORYLATION (ETC)

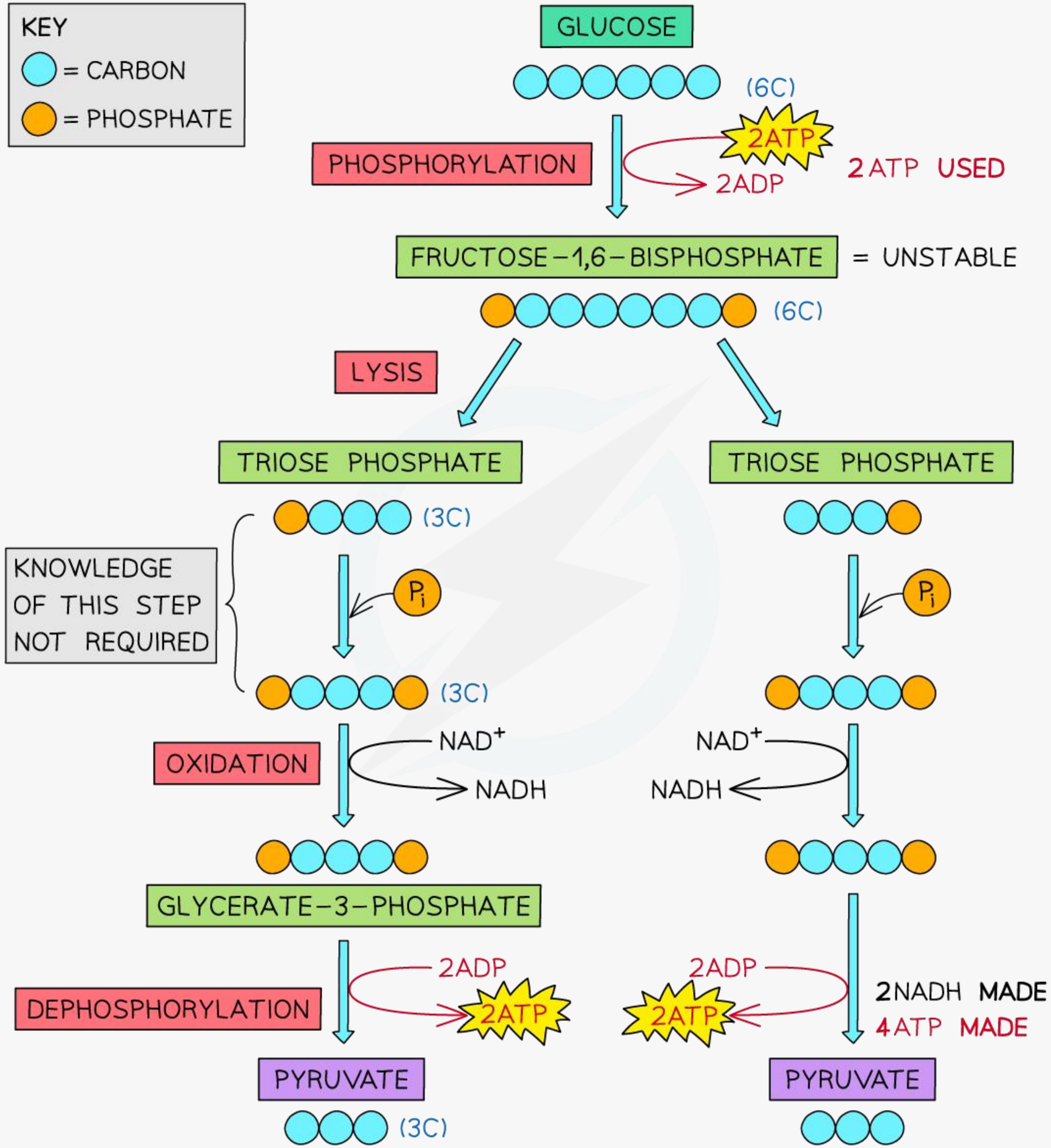
GLYCOLYSIS

GLYCOLYSIS

- “Splitting of glucose”
- It happens in the cytoplasm, even with the absence of Oxygen.
- In this process, it breaks down the glucose into **2 Pyruvate,** it also yields **4 ATP, and 2 NADH**.

GLYCOLYSIS

- **Detailed steps:**
  1. Phosphorylation of glucose using **2 ATP**.
  2. After adding a phosphate group, it is converted into **two 3-carbon molecule called PGAL (Phosphoglyceraldehyde) or G3P**
  3. Another phosphate group is added to the PGAL, and a hydrogen atoms are transferred to NAD+ which forms **2 NADH**.
  4. PGAL's phosphate group is broken down and forms into **2 ATP** and converts into **2 pyruvate.**


KEY
= CARBON
= PHOSPHATE
GLUCOSE
(6C)
PHOSPHORYLATION
2ATP
2ADP
2 ATP USED
FRUCTOSE–1,6–BISPHOSPHATE
= UNSTABLE
(6C)
LYSIS
TRIOSE PHOSPHATE
TRIOSE PHOSPHATE
(3C)
KNOWLEDGE OF THIS STEP NOT REQUIRED
P_i
P_i
(3C)
OXIDATION
NAD^+
NADH
NAD^+
NADH
GLYCERATE–3–PHOSPHATE
DEPHOSPHORYLATION
2ADP
2ATP
2ADP
2ATP
2 NADH MADE
4 ATP MADE
PYRUVATE
PYRUVATE
(3C)

- If the oxygen is present in the glycolysis, it can proceed to Aerobic Respiration.
- The pyruvate or pyruvic acid must move across the mitochondrion’s membrane and into the matrix.
- These pyruvic acid will be converted into an intermediate molecule called acetyl coenzyme A (Acetyl-CoA) by losing CO2 and a hydrogen ion which forms a 2-carbon Acetyl group.
- Combines with coenzyme A resulting to form an Acetyl-CoA which will then be proceed to the next stage which is the Kreb Cycle (Transition Stage).

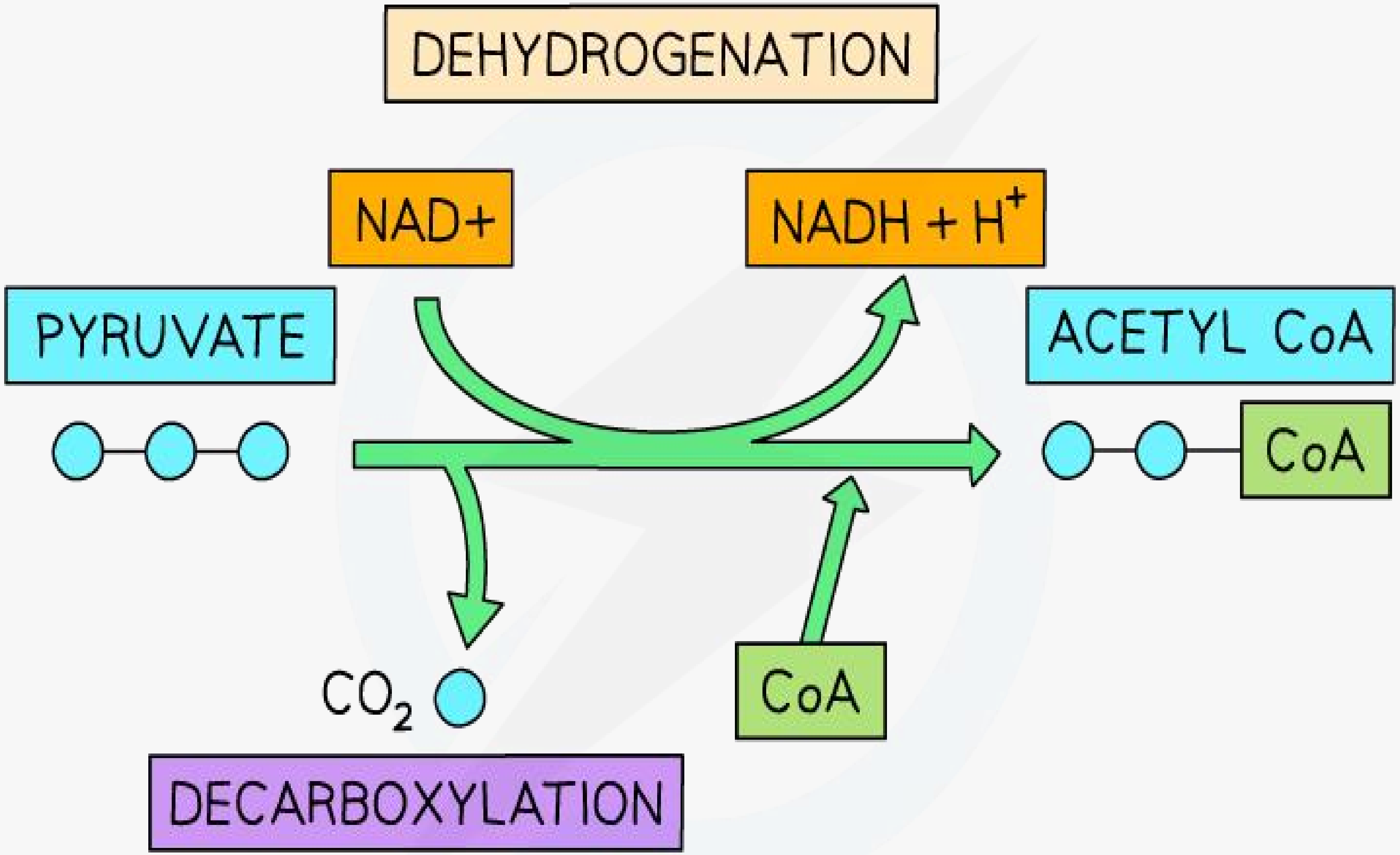
KREB’S CYCLE

KREB'S CYCLE

- **TRANSITION STAGE (Link Reaction)**
  - It is where the pyruvic acid converted into an intermediate molecule called ***Acetyl-CoA****.*
  - The 3-carbon molecule loses a CO2 and a hydrogen ion resulting to form NADH, which forms 2-carbon acetyl group. Each acetyl group combines with **coenzyme A.**

Acetyl-CoA

KREB'S CYCLE (Link Reaction)



KREB'S CYCLE

- **Kreb's cycle** is a series of chemical reactions that take place with the **presence of oxygen** inside the **matrix** of the mitochondrion.
- Releasing of carbon dioxide and hydrogen ions which results to produce **ATP**.
- Discovered by Hans Krebs.

KREB'S CYCLE

- **DETAILED STEPS:**
  1. The 2-carbon Acetyl CoA gets combined with a 4-carbon molecule called **Oxaloacetate** releasing the CoA and forms a 6-carbon molecule called **Citric Acid**
  2. The citric acid gets oxidized, transferring of electrons and hydrogen ions from NAD+ to form NADH. The oxidation causes also the release of a CO2. Now, we have a 5-carbon molecule called **Alpha-ketoglutarate.**

KREB'S CYCLE

- **DETAILED STEPS:**

  3. The Alpha-ketoglutarate also undergo the same process of oxidation, which NADH is formed and CO2 is released and a 4-carbon molecule called ***Succinate*** is formed.

  4. The ***succinate*** will undergo another set of chemical reaction to form a different 4-carbon molecule. In this reaction, energy is released which will be attached to an ADP and form ATP. The new 4-carbon molecule is now called ***Malate.***

KREB’S CYCLE

- **DETAILED STEPS:**

  5. The ***malate*** gets oxidized further, which there is a transferring of electron and hydrogen to a different electron carrier called FAD, and forms into a FADH2. This electron carrier serves also the same purpose as NADH, carries electrons.

  6. The remaining 4-carbon molecule (Malate) gets oxidized, for the last time. Forming another NADH and the 4-carbon molecule will be converted into a starting molecule called **Oxaloacetate,** which allows the cycle to go on.

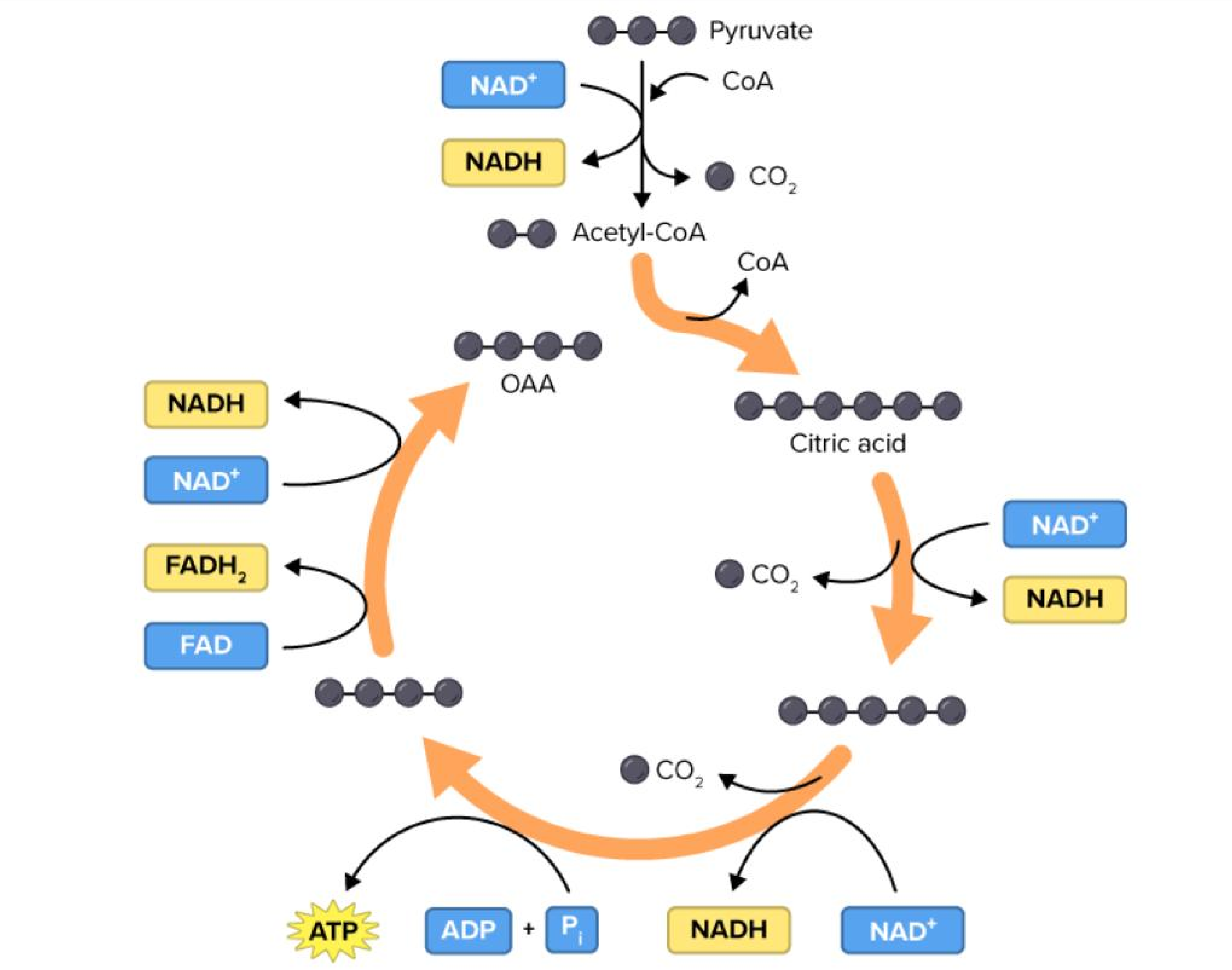
KREB'S CYCLE

- **DETAILED STEPS:**

  7. The Kreb's cycle turns twice since in the beginning there are 2 Acetyl CoA. Forming a total of **6 NADH, 2 FADH2, 2 ATPs, and 4 molecules of CO2** as byproducts.

  8. The electrons in NADH and FADH2 will be further used to generate more ATP molecules.

KREB'S CYCLE



Pyruvate
NAD+
CoA
NADH
CO2
Acetyl-CoA
CoA
OAA
Citric acid
NADH
NAD+
NAD+
CO2
NADH
FADH2
FAD
CO2
ATP
ADP
+
Pi
NADH
NAD+

ELECTRON TRANSPORT CHAIN

ELECTRON TRANSPORT CHAIN

- Electron transport chain (ETC) is the final stage of aerobic respiration. It is located on the inner mitochondrial membrane.
- **Oxidative Phosphorylation** is when the energy stored in it release within to reduce hydrogen carriers in order to synthesize ATP

ELECTRON TRANSPORT CHAIN

- Electrons travel from carrier to carrier moving toward the lower energy level of the final acceptor, which is **Oxygen.**
- NADH donates 2 electrons to the ETC chain, FADH2 also donates electrons.
- These electrons are passed on from one acceptor to another until their energy is depleted and is passed on to an **OXYGEN**

ELECTRON TRANSPORT CHAIN

- The charged oxygen will bind with a hydrogen ion (proton) that will result in the formation of **Water**.

ELECTRON TRANSPORT CHAIN

- The electrons undergo through a **chain of proteins** that increases its reduction potential and causes a release in energy.
- **ETC Proteins**: complex I, complex II, coenzyme Q, complex III, cytochrome C, and complex IV.

ELECTRON TRANSPORT CHAIN

- STEPS:

1. Electrons go to complex I and four protons pumped from matrix to intermembrane space.
2. Coenzyme Q picks up electron from complex I and complex II and transport to complex III, Four protons pumped from matrix to intermembrane space

ELECTRON TRANSPORT CHAIN

- STEPS:

3. Carrier C transports electrons to complex IV, then two protons pumped from matrix to inter-membrane space.

4. High concentration in intermembrane space and low concentration in the matrix.

ELECTRON TRANSPORT CHAIN

- STEPS:

5. Electrons get transported to the final protein complex (Complex IV), which **Oxygen** is the final acceptor of the electrons and forms **Water.**

6. ATP synthase action pumps protons from inter-membrane space to matrix (Diffusion), produces ATP from ADP + Pi + energy

ELECTRON TRANSPORT CHAIN

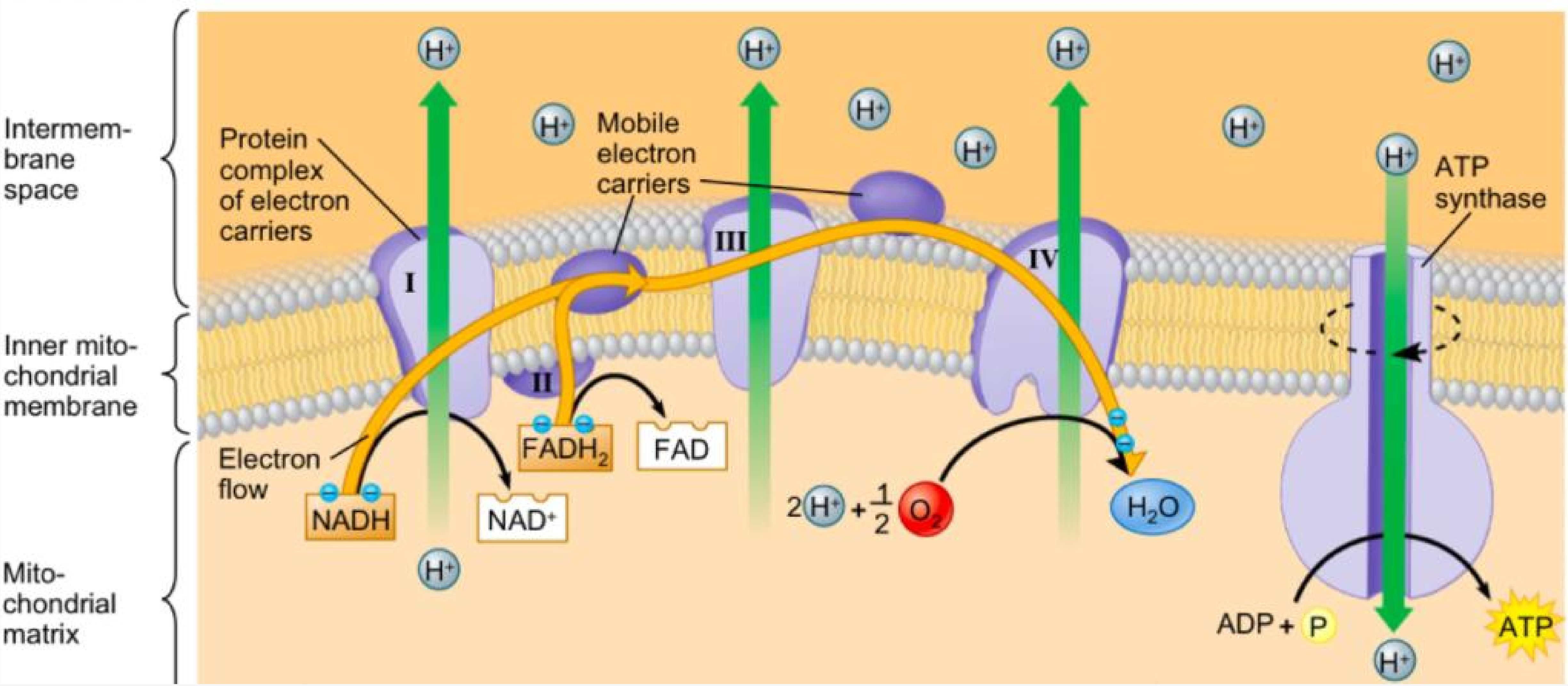
- STEPS:

7. **Chemiosmosis** describes the movement of electrons down to the matrix. Its movement is the result of the build up of hydrogen ions. Due to the change of concentration gradient, the hydrogen ions flow back to the matrix.

ELECTRON TRANSPORT CHAIN

- STEPS:

8. The flow of the hydrogen ions through ATP Synthase results in **collisions of phosphate with ADP, and forms ATP**.



Intermembrane space
Inner mitochondrial membrane
Mitochondrial matrix
Protein complex of electron carriers
Mobile electron carriers
ATP synthase
I
II
III
IV
Electron flow
NADH
NAD+
FADH2
FAD
2 H+ + 1/2 O2
H2O
H+
ADP + P
ATP

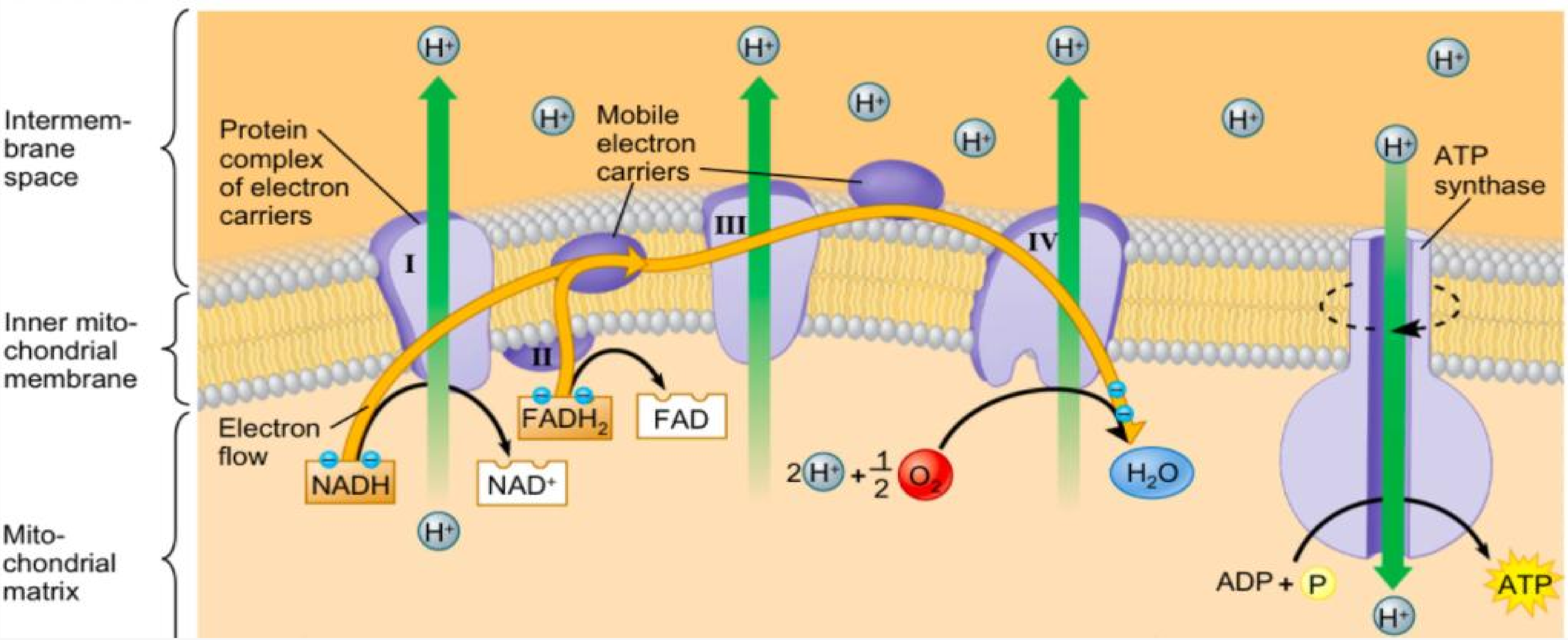
TOTAL OF ATP’S PRODUCED IN CELLULAR RESPIRATION

TOTAL OF ATP'S PRODUCED IN CELLULAR RESPIRATION

36 ATP

ACTIVITY 3.4: THE LAST STAGE

Using the figure below, arrange the proper sequence of the electron transport chain process. Use number 1 as the first event and 7 as the last event.



A.

Electrons from Complex I and Complex II are transferred to a carrier called ubiquinone Q. This molecule carries the electrons to Complex III.

B.

$FADH_2$ from glycolysis and Krebs cycle is oxidized to FAD by Complex II. It also releases H^+ ions into the intermembrane space and passes off electrons.

C.

In Complex I, NADH from glycolysis and Krebs cycle are oxidized to NAD+. It passes off 2 electrons and H+ ions are pumped into the intermembrane space.

D.

Complex III accepts the electrons brought in by ubiquinone Q and pumps more H^+ ions into the intermembrane space.

E.

In Complex IV, a reaction with O_2 produces H_2O. More H^+ ions are pumped into the intermembrane space. By now, the concentration of H^+ ions is very high.

F.

H^+ ions need to cross the membrane to balance the concentration gradient. They use ATP Synthase to do this. As the ions pass through, the pump makes ATP.

G.

Electrons in Complex III are picked up by cytochrome C, another carrier molecule. This molecule carries the electrons to Complex IV.

FERMENTATION

FERMENTATION

- **Fermentation** is the process of glycolysis that provides ATP molecules, but does not require oxygen. Recall that 2 ATPs are produced for each glucose molecule that is broken down to pyruvic acid.

FERMENTATION

- **TYPES OF FERMENTATION**

  A. Lactic Acid Fermentation
  B. Alcohol Fermentation

FERMENTATION

• LACTIC ACID FERMENTATION

In lactic acid fermentation, **enzymes** help convert pyruvic acid generated during glycolysis into lactic acid. This chemical reaction happens in the cytoplasm of the cell.

Purpose:

- To generate ATP quickly when oxygen is scarce.
- To regenerate NAD^+ from NADH, which is necessary for glycolysis to continue.

FERMENTATION

Process Overview:

1. **Glycolysis**: The process begins with glycolysis, where one molecule of glucose (6 carbons) is broken down into two molecules of pyruvate (3 carbons), yielding a net gain of 2 ATP and 2 NADH.
2. **Conversion to Lactic Acid**: In the absence of oxygen, the pyruvate is converted into lactic acid by the enzyme lactate dehydrogenase. During this reaction, the NADH is oxidized back to NAD^+ .

FERMENTATION

- ALCOHOL FERMENTATION

A. Alcohol fermentation is the process through which sugars are converted to energy.

B. Yeast is used to produce alcoholic beverages such as beer and wine, it contains the enzyme *<u>Decarboxylase</u>*.

C. The fermentation process occurs in cytosol of the yeast cells. This enzyme removes the terminal carbon, thus, turning the 3-carbon pyruvate into 2-carbon acetaldehyde, which is reduced to ethyl alcohol by NADH.

FERMENTATION

Purpose:

- \- To produce ATP in the absence of oxygen.
- \- To regenerate NAD^+ , which allows glycolysis to continue

FERMENTATION

Process Overview:

1. **Glycolysis**: The process starts with glycolysis, where one molecule of glucose is broken down into two molecules of pyruvate, yielding 2 ATP and 2 NADH.

2. **Conversion to Ethanol**: The pyruvate is then converted into ethanol and carbon dioxide through a two-step process:

   2.1: ***Decarboxylation***: Pyruvate is converted into acetaldehyde, releasing carbon dioxide.

   2.2: ***Reduction***: Acetaldehyde is reduced to ethanol by the enzyme alcohol dehydrogenase, utilizing NADH.

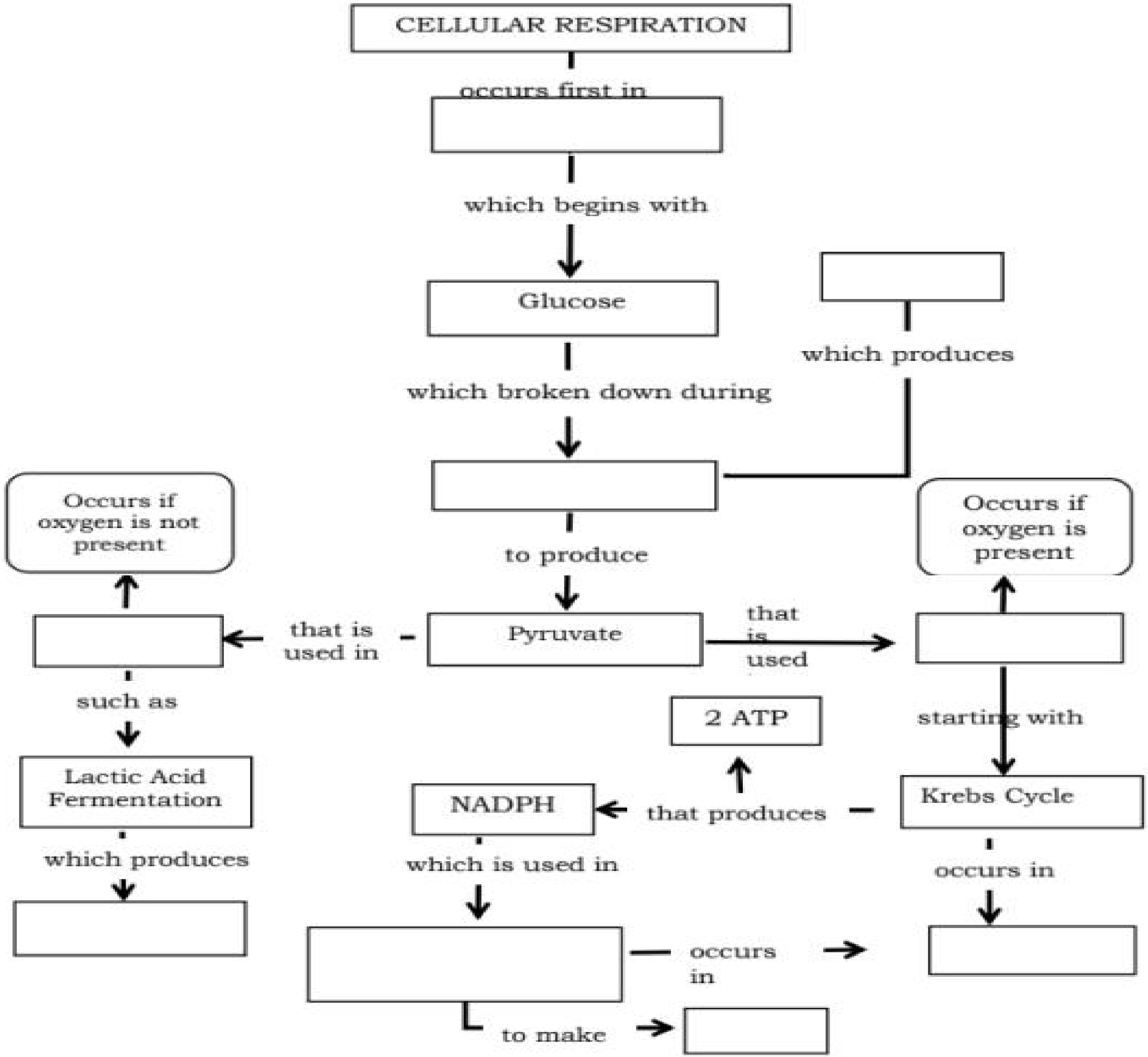
ACTIVITY 4.1: WHAT MAKES ME DIFFERENT?

COMPARATIVE FEATURES	CHOICES	PHOTO-SYNTHESIS	CELLULAR RESPIRATION
Occurs in	Plants		
	All living things		
	Algae		
	Photosynthetic bacteria		
Function/ Purpose	Release energy		
	Capture, convert and store energy		
Reactants	Water		
	Glucose		
	Oxygen		
	Carbon dioxide		
	Light energy		
Metabolic Process	Catabolic		
	Anabolic		
Location	Mitochondria		
	Chloroplast		
	Cytoplasm		
Source of Energy	Glucose		
	Sunlight		
Stages	Light- dependent Reactions		
	Calvin Cycle,		
	Glycolysis		
	Krebs cycle		
	Electron Transport Chain		
Products	Water		
	Oxygen		
	Glucose		
	Carbon dioxide		
Equation	$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$		
	$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$		

GUIDE QUESTIONS:

1. How are photosynthesis and cellular respiration dependent on each other?
2. How important are photosynthesis and cellular respiration?

ACTIVITY 4.2: CONCEPTUALIZE


CELLULAR RESPIRATION
occurs first in
which begins with
Glucose
which broken down during
which produces
to produce
Occurs if oxygen is not present
Occurs if oxygen is present
that is used in
Pyruvate
that is used
such as
2 ATP
starting with
Lactic Acid Fermentation
NADPH
that produces
Krebs Cycle
which produces
which is used in
occurs in
occurs in
to make