Cellular respiration

BTEC 101

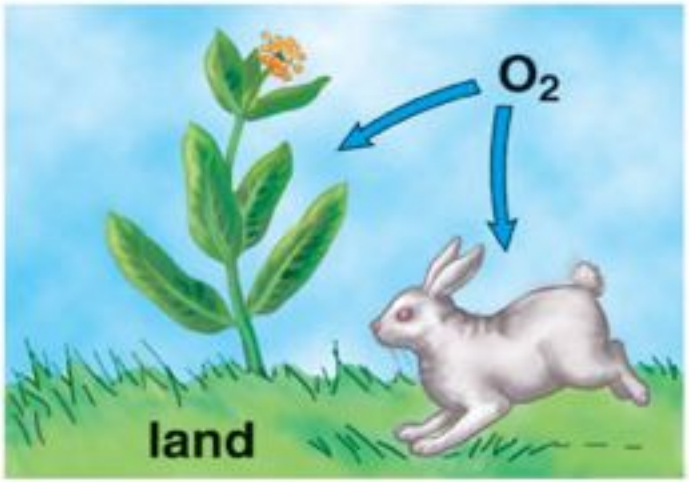
Aerobic Fermentation

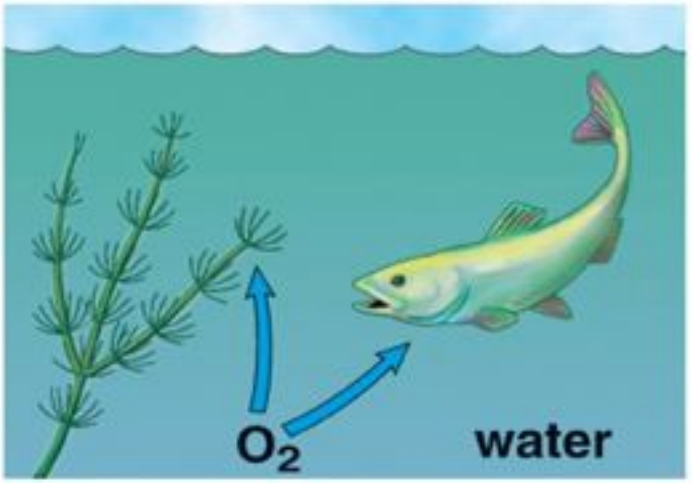
Bacterial Metabolism

- To make energy, a cell uses the following pathways:
  - Glycolysis
  - Krebs Cycle (Citric Acid Cycle or Tricarboxylic acid cycle TCA)
  - Electron Transport Chain (oxidative phosphorylation)
- High energy molecules ($):
  - ATP, NADH, and FADH2

Note!

Cellular respiration: Purpose

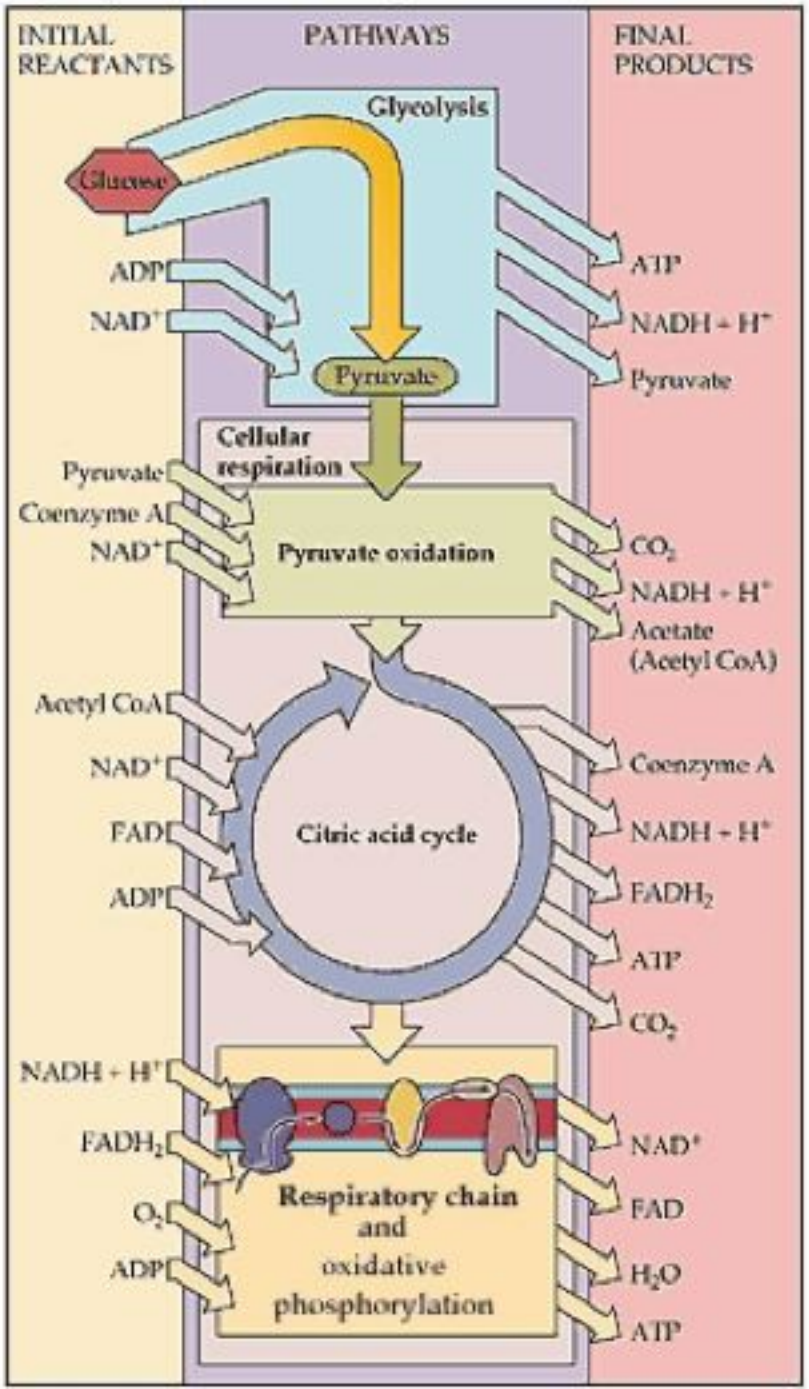




$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6CO_2 + 6H_2O$$

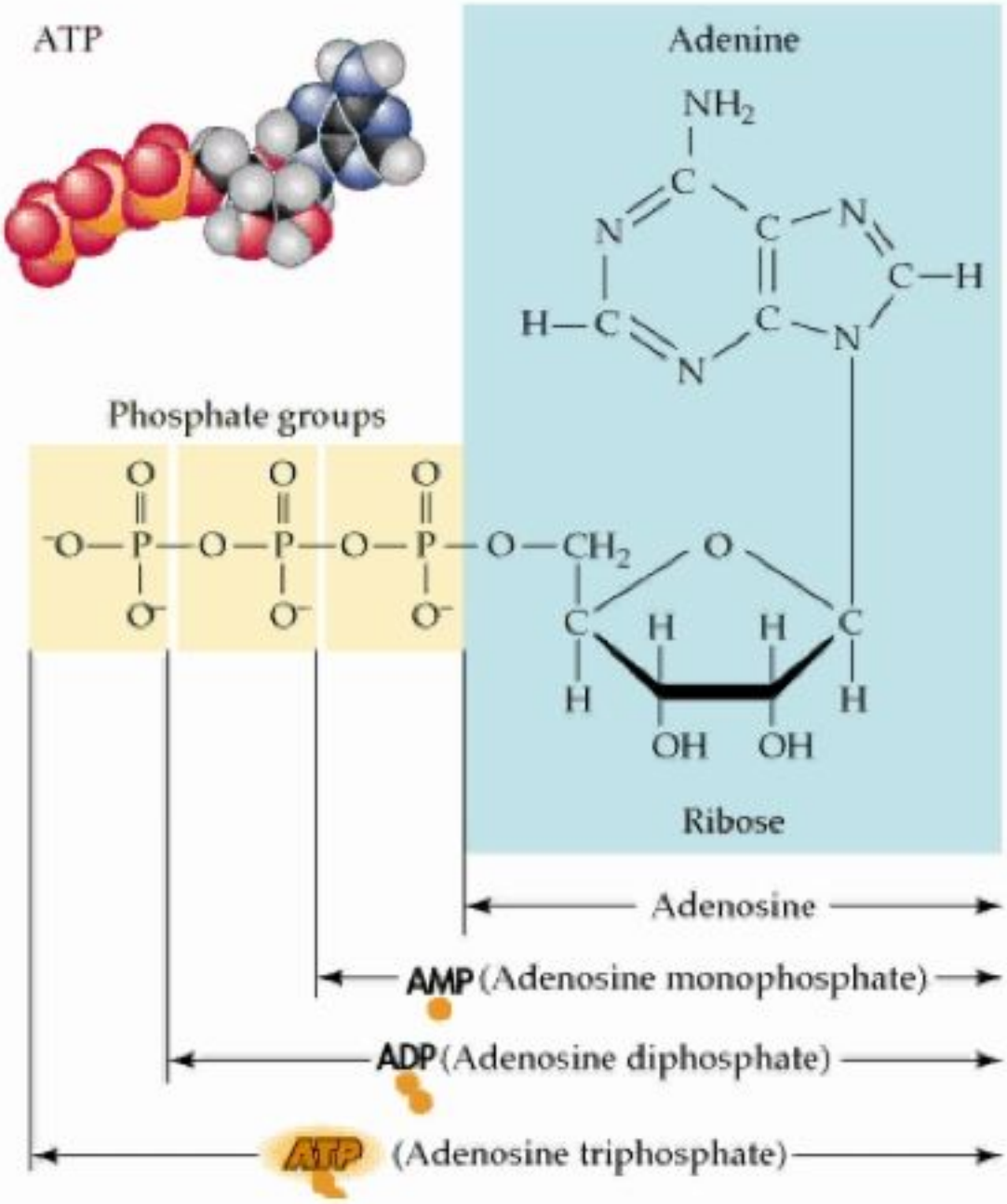
glucose + oxygen → carbon dioxide + water

Glycolysis and cellular respiration



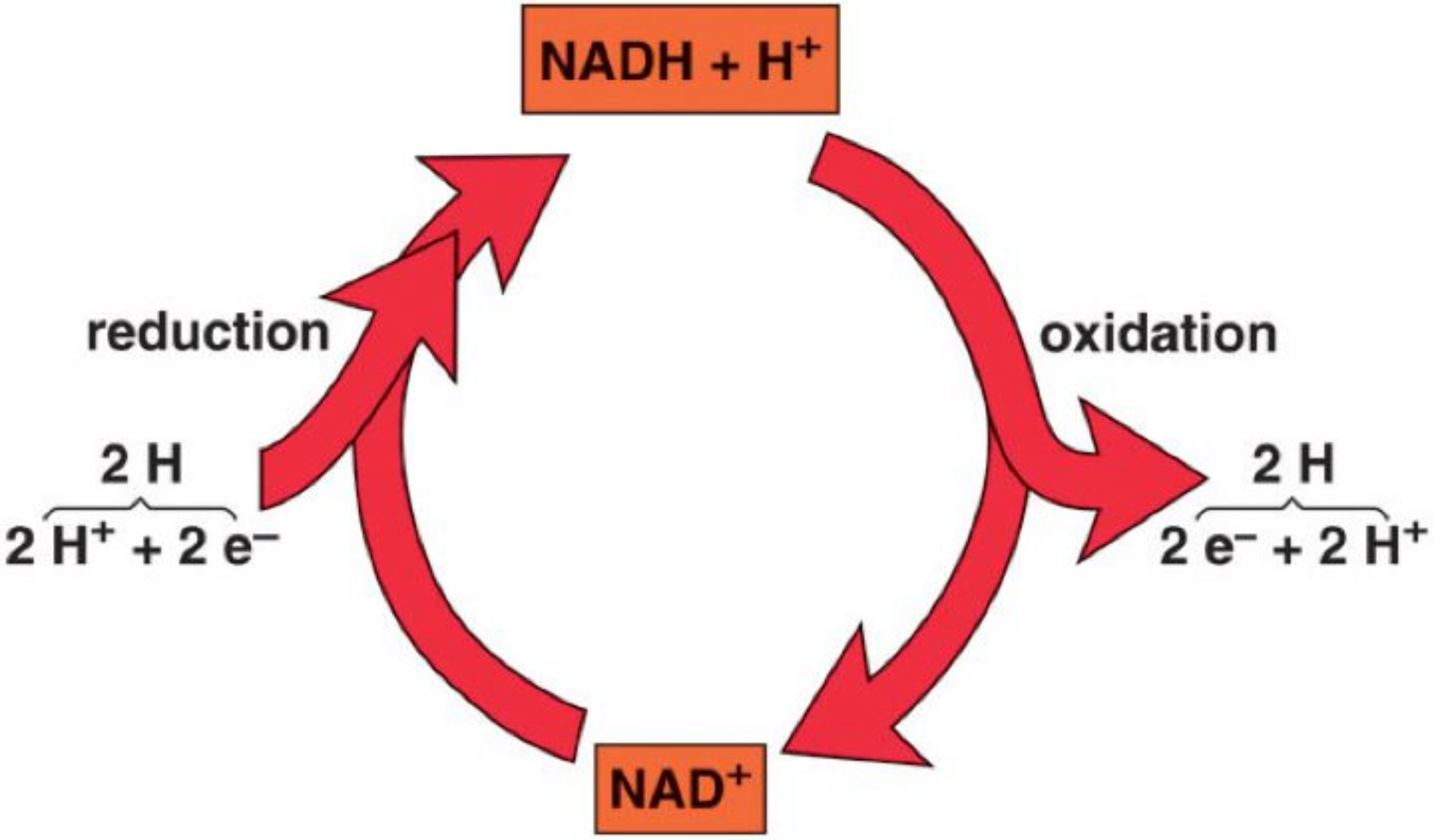
Energy for cells

- Cells store energy in a molecule called adenosine triphosphate (abbreviated as ATP).
  - The adenosine molecule has three phosphate groups attached to it (*tri*phosphate means three phosphates) which are held together by high energy bonds.
  - If one of these bonds is broken, a great amount of energy is released which can be used in an endergonic reaction.
- The main source of energy for living organisms is a sugar called glucose.
  - In breaking down glucose, the energy in the glucose molecule's chemical bonds is released and can be harnessed by the cell to form ATP molecules.


ATP
Adenine
Phosphate groups
Ribose
Adenosine
AMP (Adenosine monophosphate)
ADP (Adenosine diphosphate)
ATP (Adenosine triphosphate)

Basic Concepts

- **Oxidation**: A reaction that involves the overall loss of electrons from a specific molecule or atom
  - Removal of electrons or hydrogens
  - Addition of an oxygen
- **Reduction**: A reaction that involves the overall gain of electrons from a specific molecule or atom
  - Addition of electrons or hydrogens
  - Removal of an oxygen



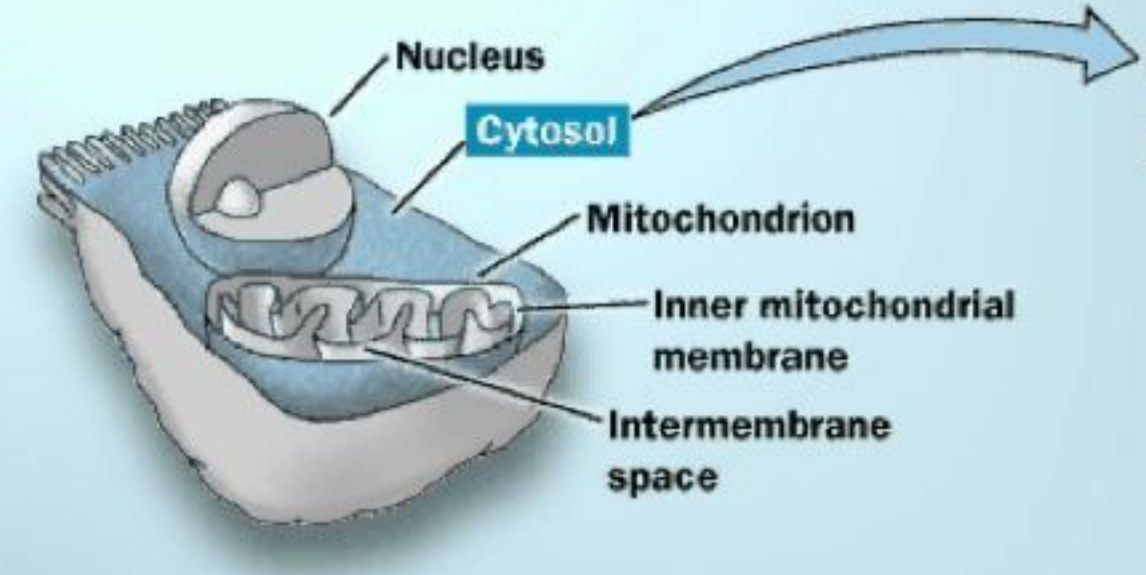
nicotinamide adenine dinucleotide = Co-enzyme

Glycolysis: The Universal Energy Pathway

- The prefix glyco refers to glucose, and lysis means to split
- Works by extracting energy from nutrient molecules (glucose)
  - in which the glucose molecule is broken down into two smaller molecules called pyruvic acid.
- Is carried out by all living cells
- Produces energy without the involvement of oxygen

Glycolysis

- Glucose is a central ATP producing pathway
- Converts Glucose → 2 pyruvates
  - Uses 2 ATP
  - Generates 4 ATP
  - Generates 2 NADH



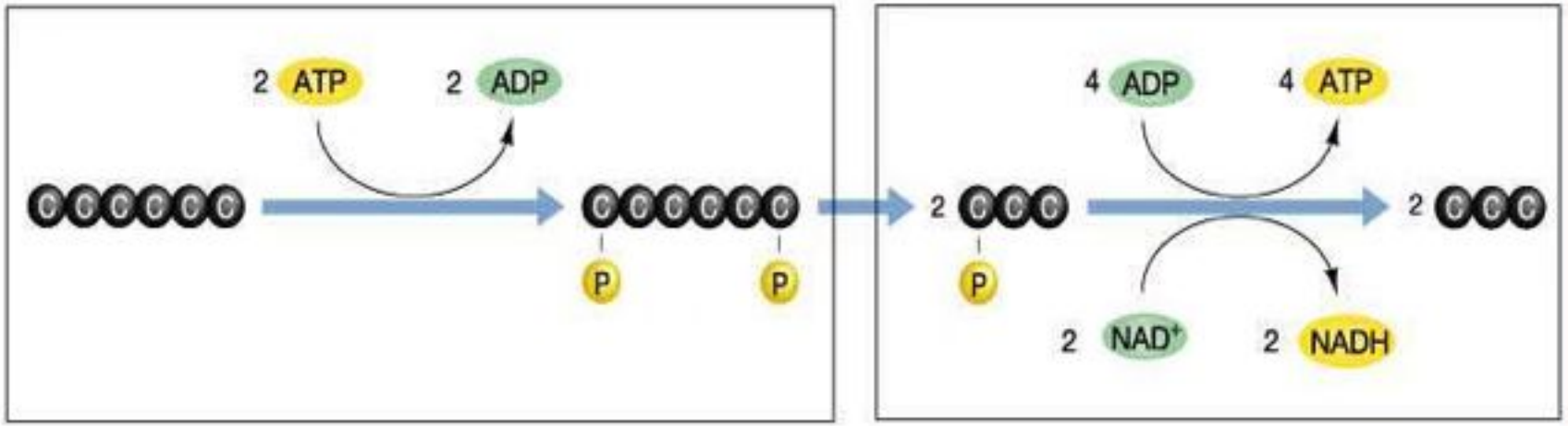
Glycolysis takes place in the cytosol

2 ADP + 2 P_i → 2 ATP

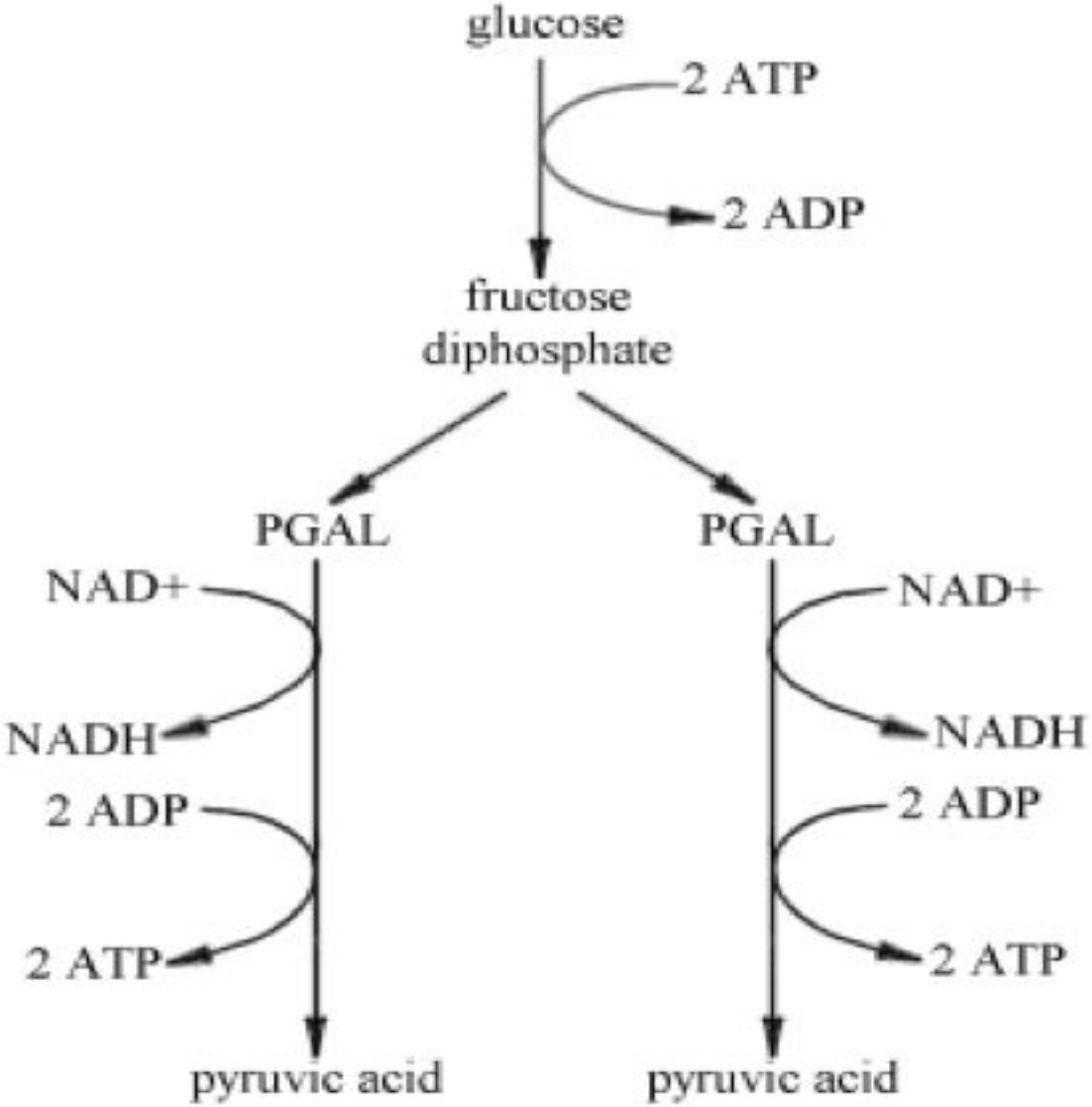
Glucose (6 carbons) → 2 Pyruvate (3 carbons each)

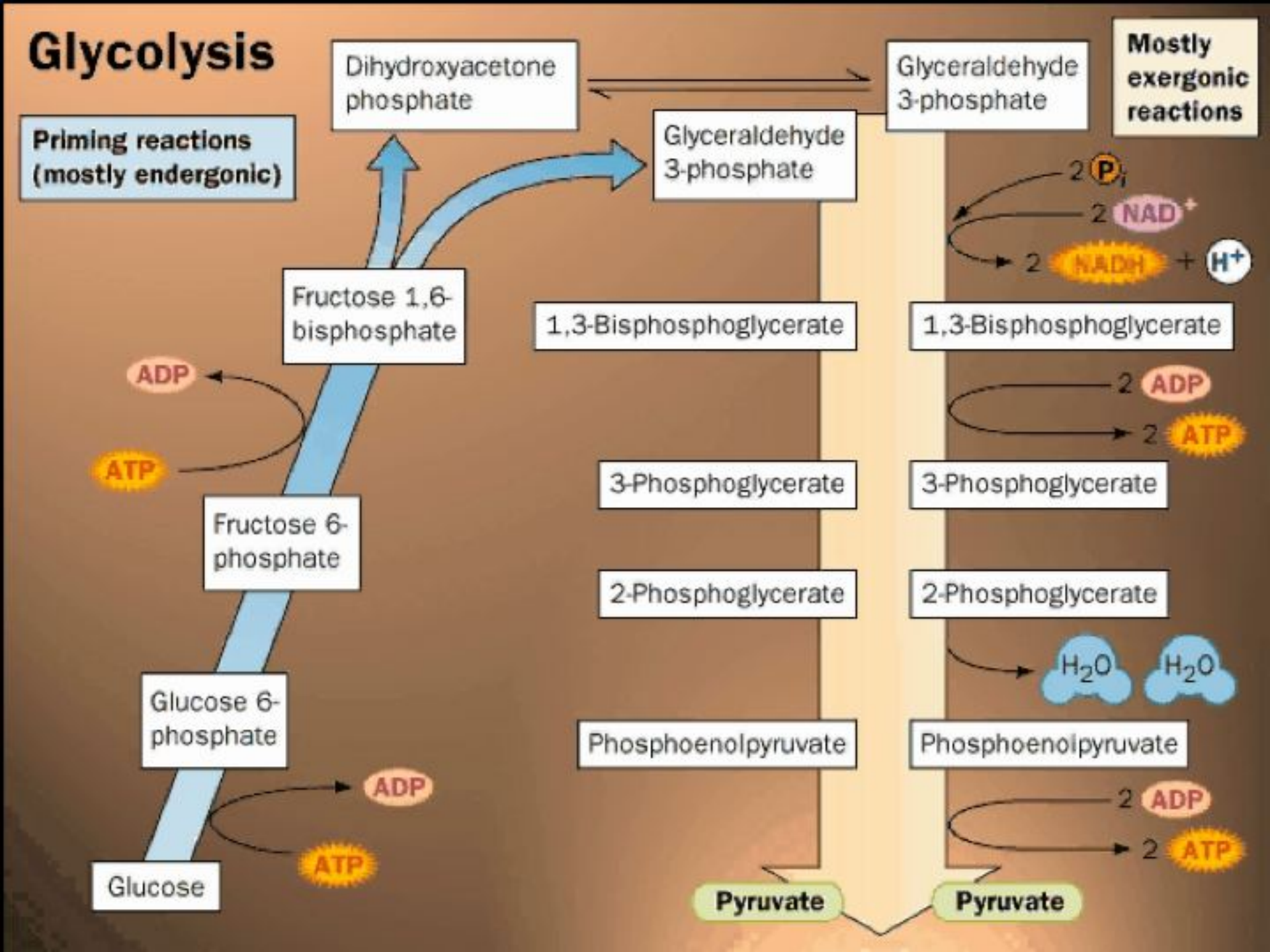
2 NAD^+ → 2 NADH + 2 H^+

Glycolysis

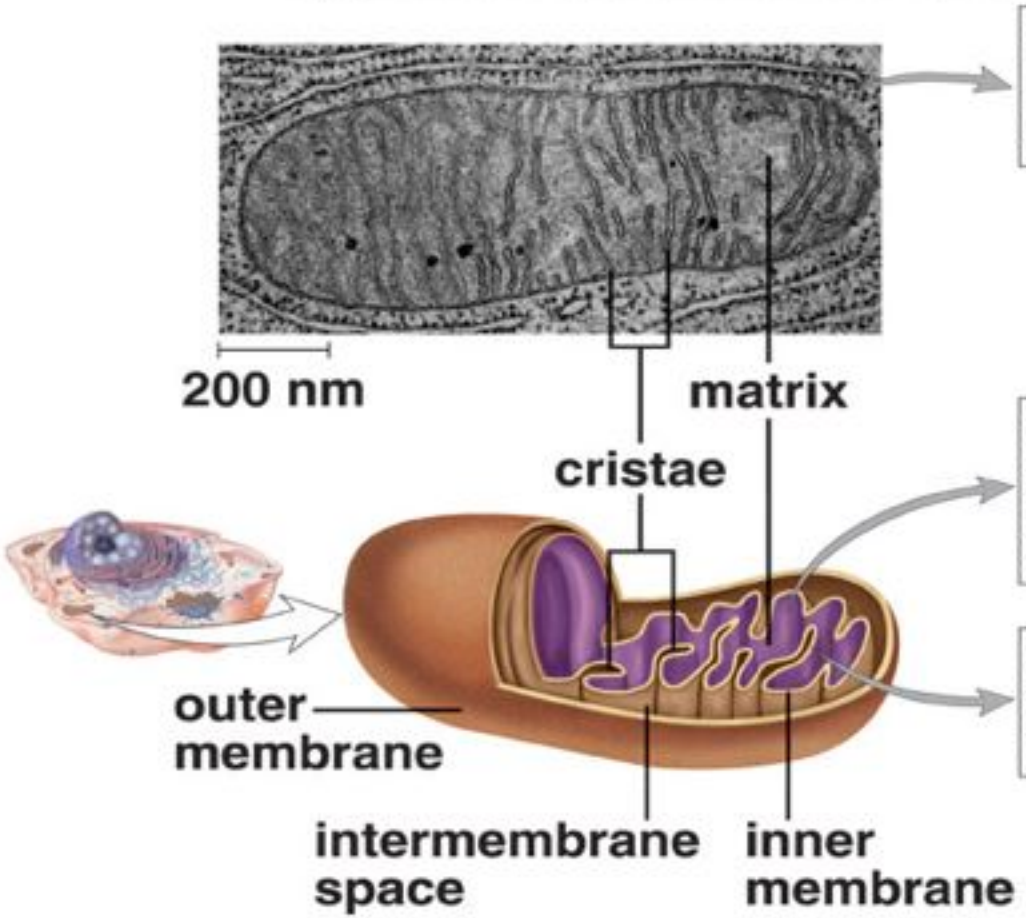


Glycolysis


glucose
2 ATP
2 ADP
fructose
diphosphate
PGAL
PGAL
NAD+
NAD+
NADH
NADH
2 ADP
2 ADP
2 ATP
2 ATP
pyruvic acid
pyruvic acid


Glycolysis
Priming reactions (mostly endergonic)
Dihydroxyacetone phosphate
Glyceraldehyde 3-phosphate
Mostly exergonic reactions
Glyceraldehyde 3-phosphate
2 P_i
2 NAD+
2 NADH + H+
Fructose 1,6-bisphosphate
1,3-Bisphosphoglycerate
1,3-Bisphosphoglycerate
ADP
ATP
2 ADP
2 ATP
Fructose 6-phosphate
3-Phosphoglycerate
3-Phosphoglycerate
2-Phosphoglycerate
2-Phosphoglycerate
H_2O
H_2O
Glucose 6-phosphate
Phosphoenolpyruvate
Phosphoenolpyruvate
ADP
ATP
2 ADP
2 ATP
Glucose
Pyruvate
Pyruvate

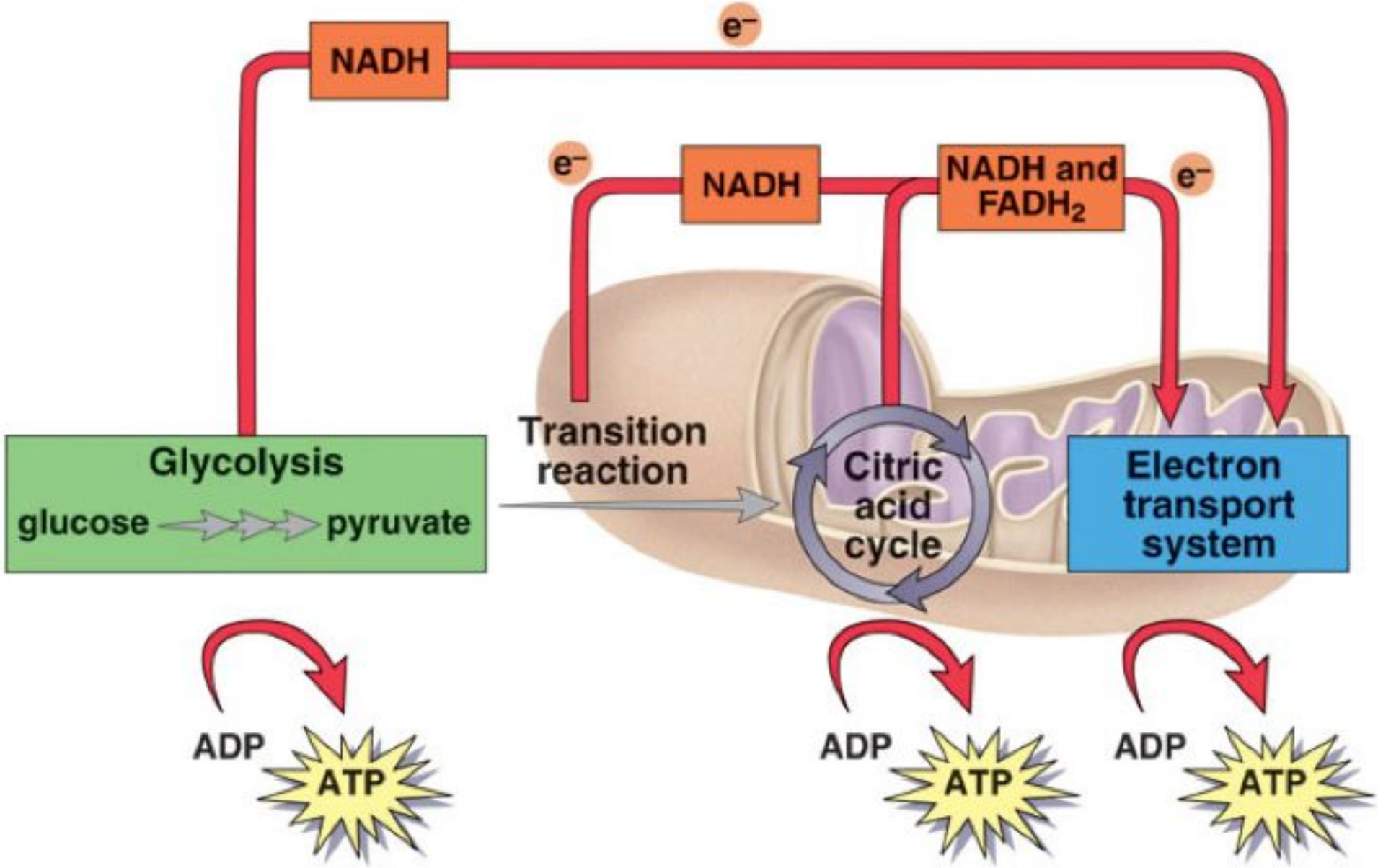
Cellular respiration: location



Cytoplasm: location of glycolysis

Matrix: location of the transition reaction and the citric acid cycle

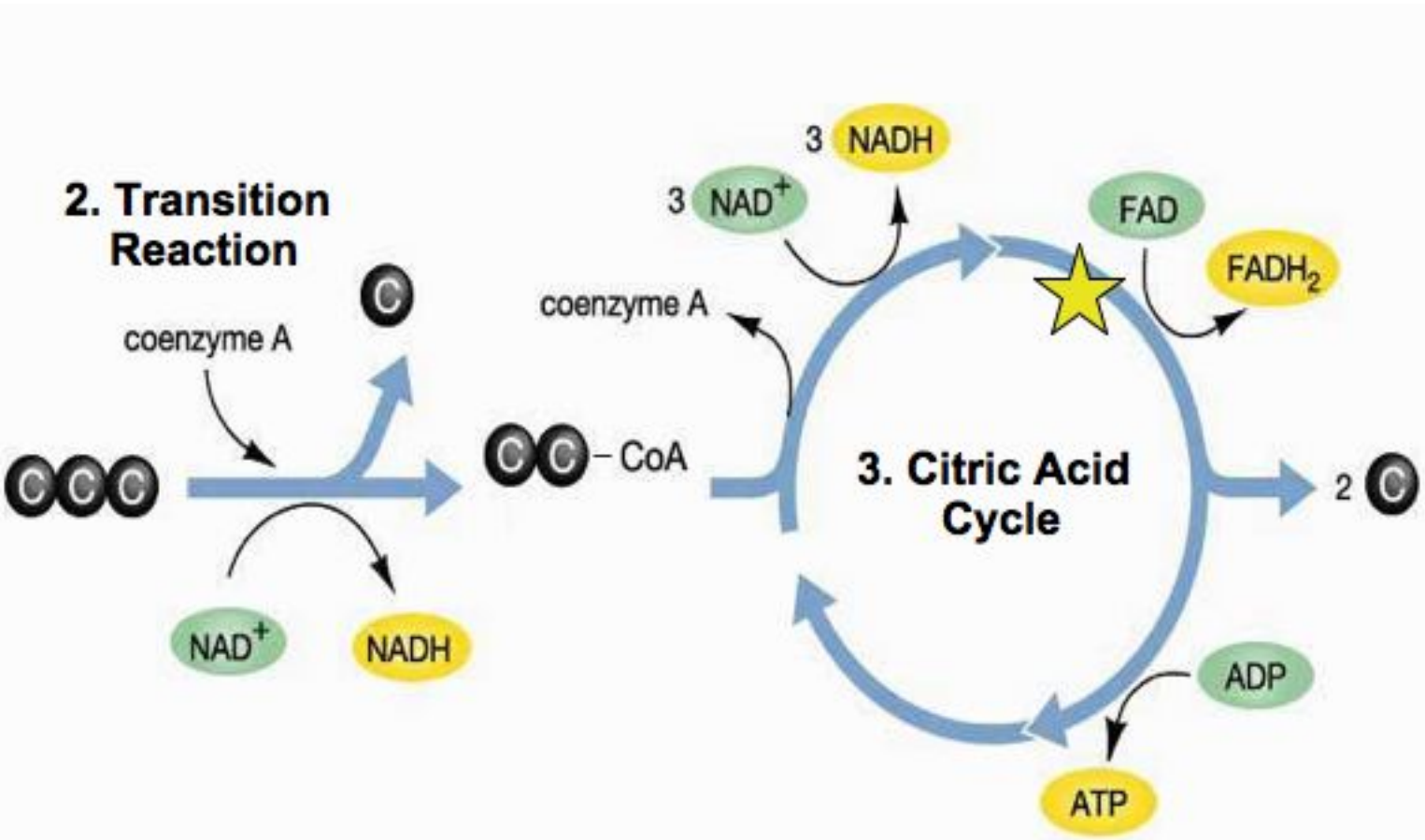
Cristae: location of the electron transport system



Pyruvate oxidation

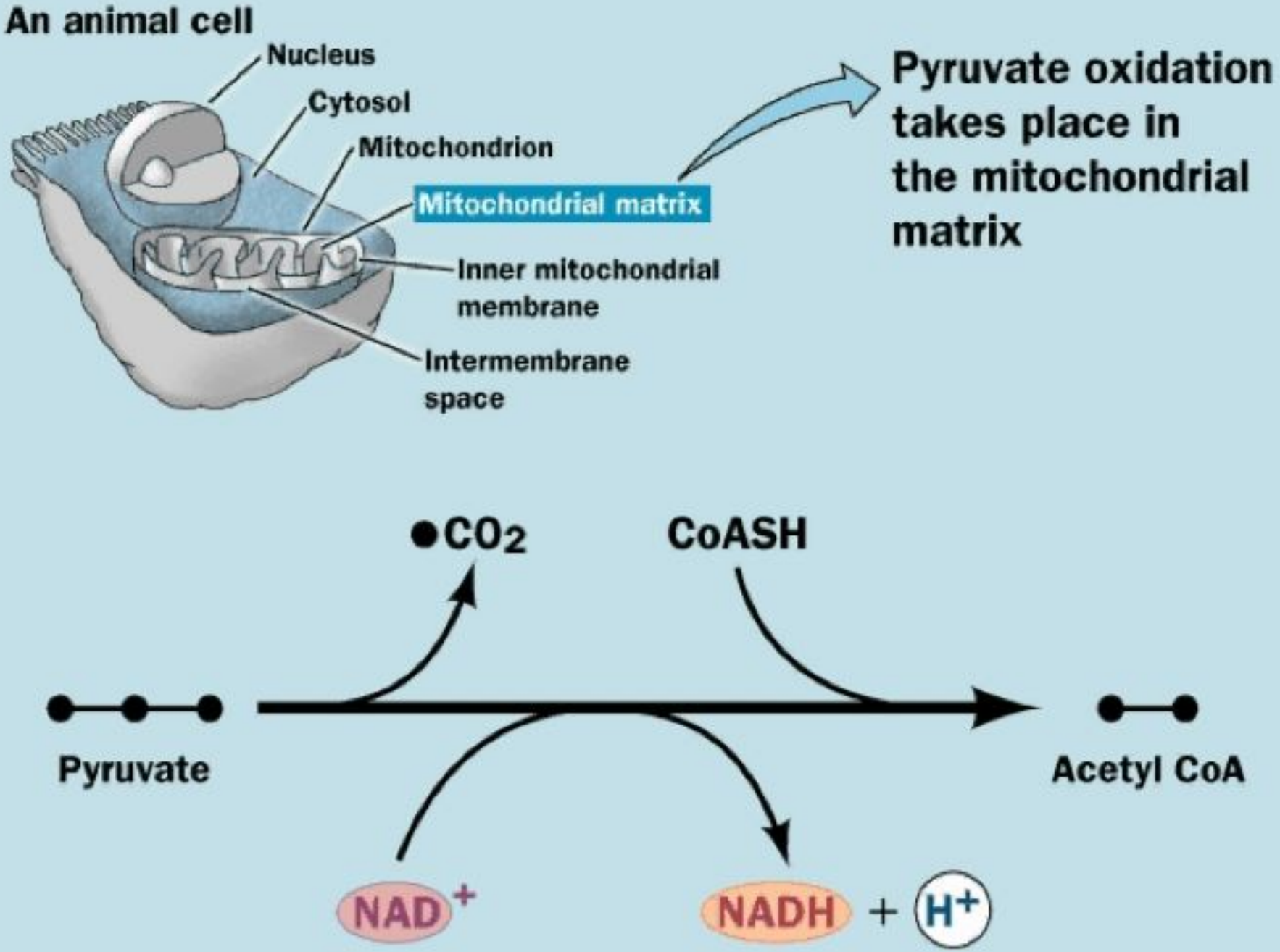
- In order for the pyruvic acid molecules from glycolysis to enter the Krebs cycle, they must first undergo one additional chemical reaction called the oxidation of pyruvic acid.
- In this reaction, one carbon atom and two oxygen atoms are removed, forming CO_2 (carbon dioxide).
- In addition, a molecule of the coenzyme NAD+ becomes NADH in the process.
- The remaining molecule has two carbons and is known as acetyl coenzyme A and has a molecular formula of CH_3CO.
- Remember, this process happens to both of the two pyruvic acid molecules formed during glycolysis.

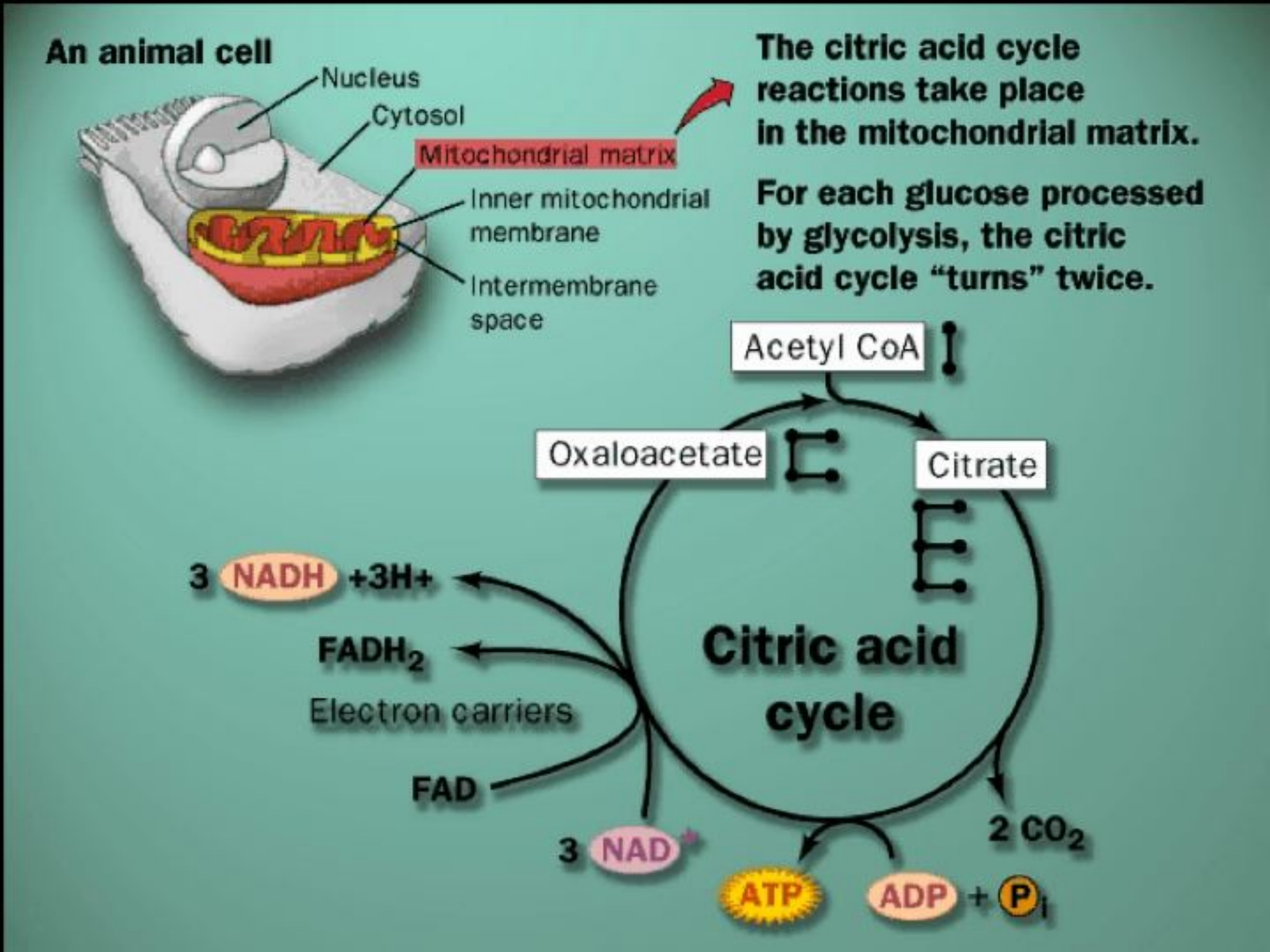
Citric Acid Cycle

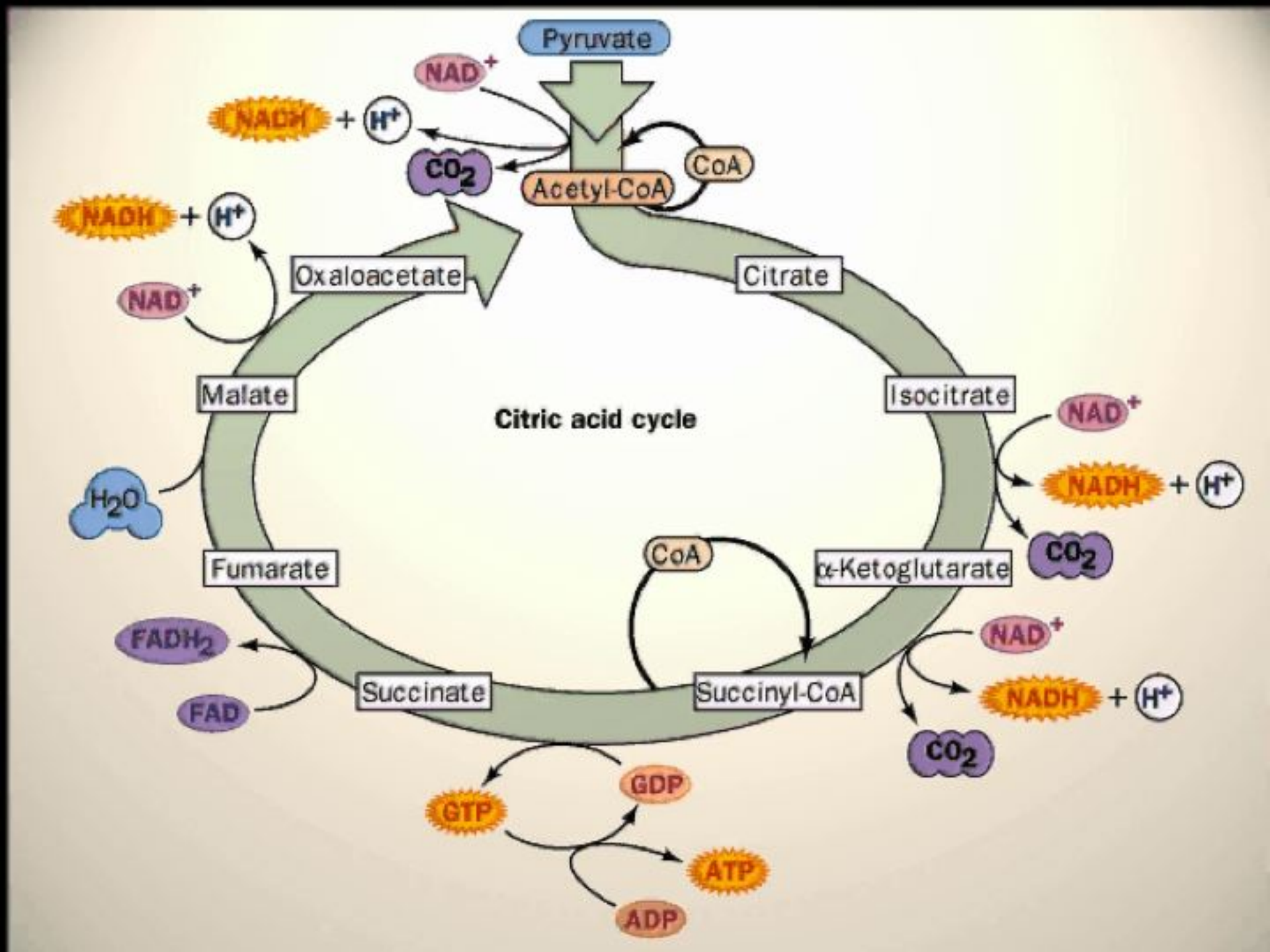


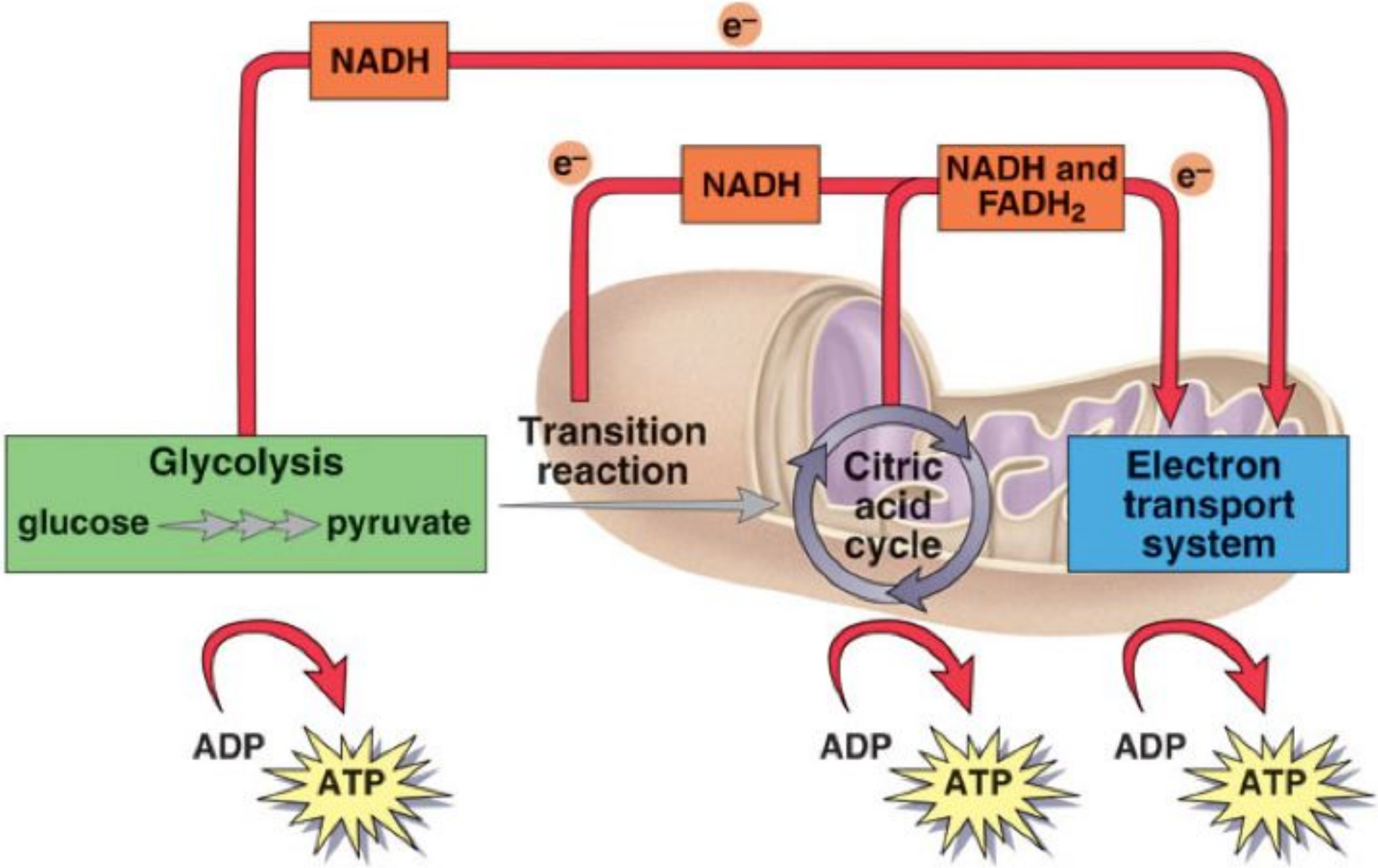
The Citric Acid Cycle

- Occurs in the mitochondria
- Results in the formation of ATP and other molecules which undergo further reactions to form more ATP.
- In general, the Krebs cycle consists of the bonding of the two carbon acetyl coenzyme A with the four carbon compound called oxaloacetic acid.
- The resulting compound, which has six carbon atoms, undergoes a series of chemical reactions (which are outlined below), resulting in the formation of energy (in the form of ATP, NADH, and FADH2) and oxaloacetic acid, which can then bond with another molecule of acetyl coenzyme A so that the cycle can run again.


An animal cell
Nucleus
Cytosol
Mitochondrion
Mitochondrial matrix
Inner mitochondrial membrane
Intermembrane space
Pyruvate oxidation takes place in the mitochondrial matrix
CO_2
CoASH
Pyruvate
Acetyl CoA
NAD^+
NADH + H^+

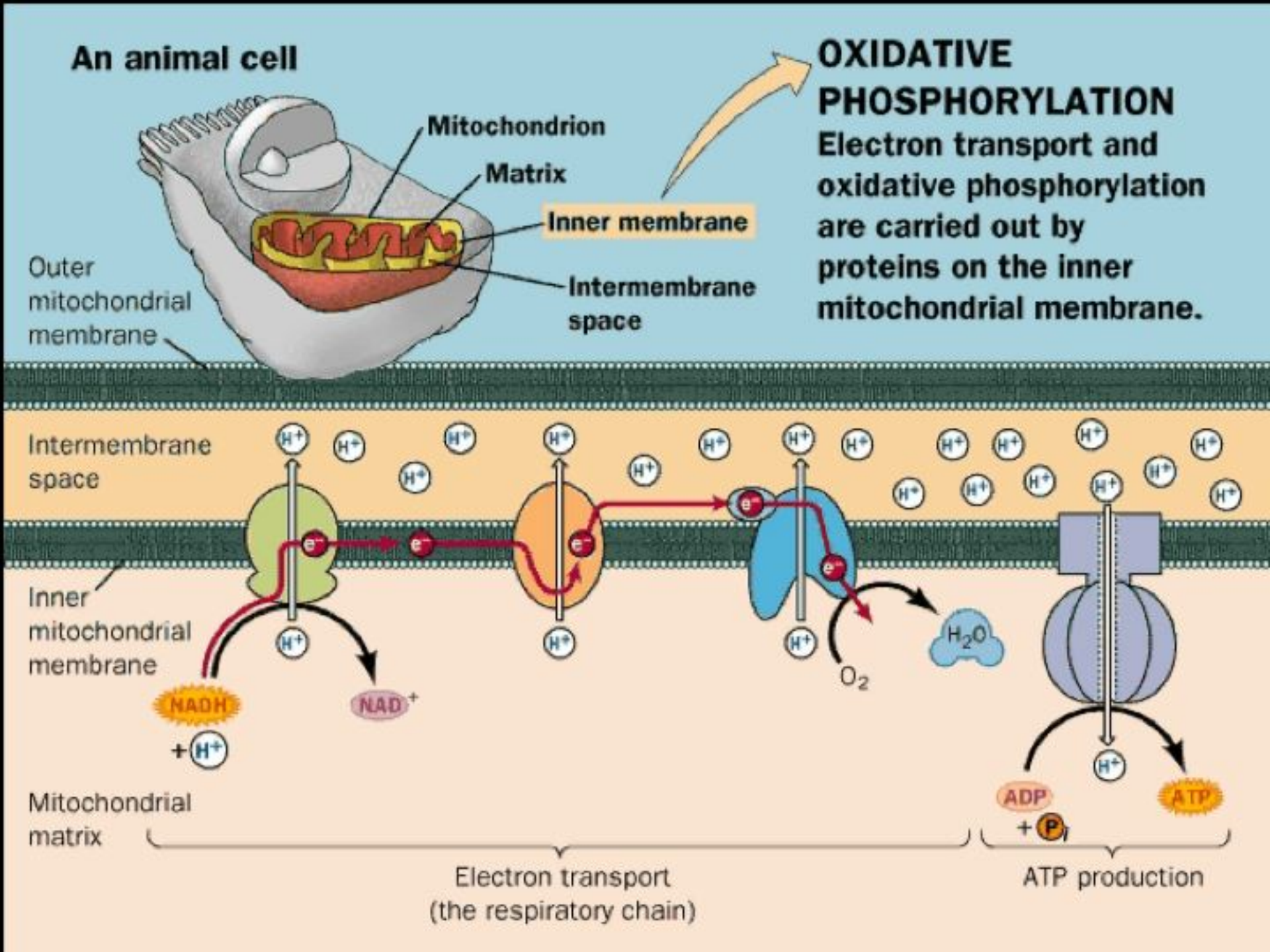

An animal cell
Nucleus
Cytosol
Mitochondrial matrix
Inner mitochondrial membrane
Intermembrane space
The citric acid cycle reactions take place in the mitochondrial matrix.
For each glucose processed by glycolysis, the citric acid cycle "turns" twice.
Acetyl CoA
Oxaloacetate
Citrate
3 NADH +3H+
FADH2
Electron carriers
FAD
Citric acid cycle
3 NAD+
2 CO2
ATP
ADP + Pi

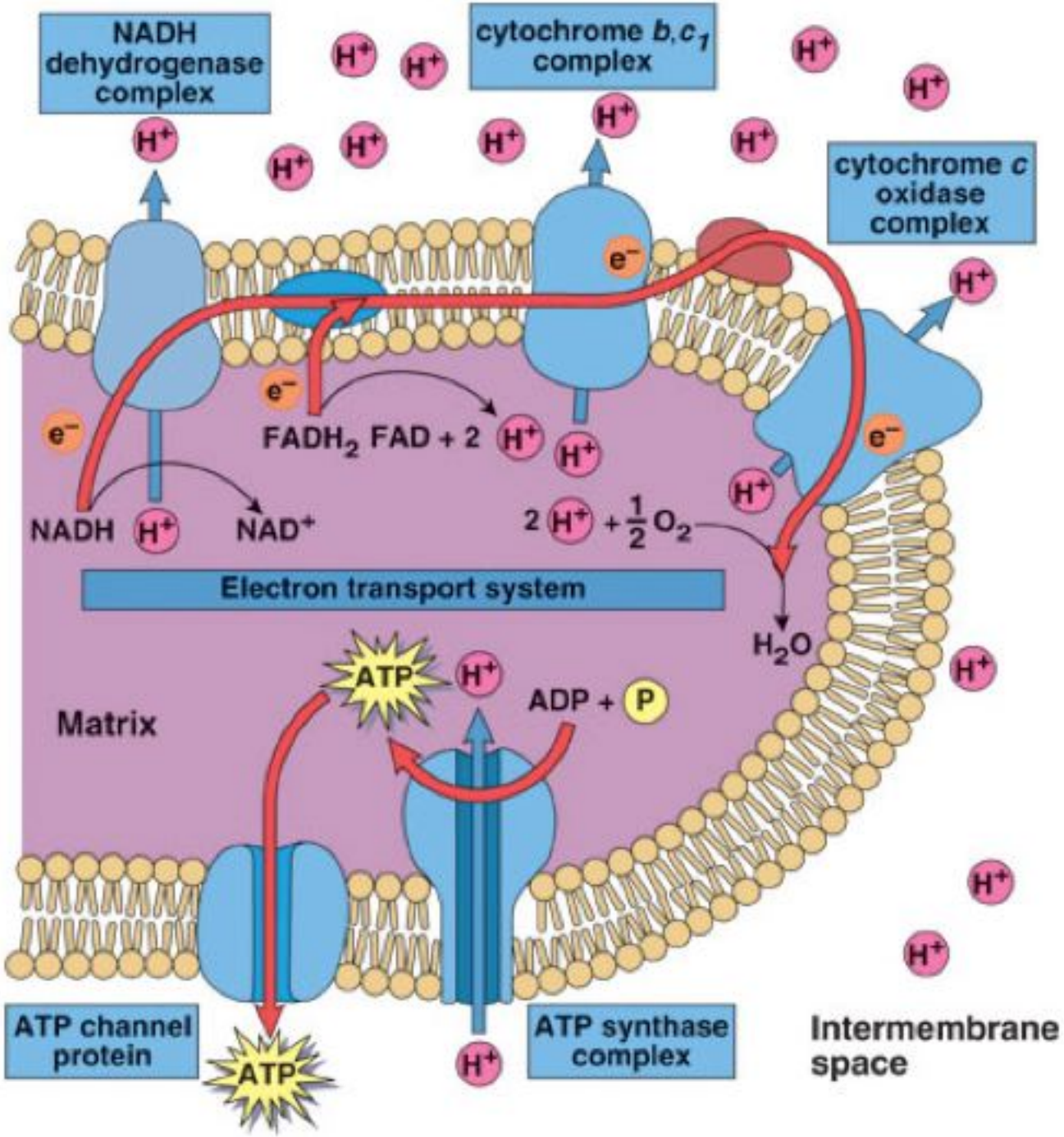

Pyruvate
NAD+
NADH + H+
CO2
CoA
Acetyl-CoA
NADH + H+
NAD+
Oxaloacetate
Citrate
Malate
Isocitrate
Citric acid cycle
H2O
NAD+
NADH + H+
CO2
CoA
Fumarate
α-Ketoglutarate
FADH2
FAD
Succinate
Succinyl-CoA
NAD+
NADH + H+
CO2
GDP
GTP
ATP
ADP



Electron Transport Chain

- Final stage of aerobic respiration
- Utilizes the NADH and $FADH_2$ from glycolysis and Krebs Cycle to generate 32-34 ATPs
- Uses Hydrogen ion concentration gradient to pass electrons from high to low energy levels, releasing energy to drive ATP synthesis
- ATP synthase
- Intermembrane space
- 1 NADH → 3 ATP
- 1 $FADH_2$ → 2 ATP
- Oxidative Phosphorylation

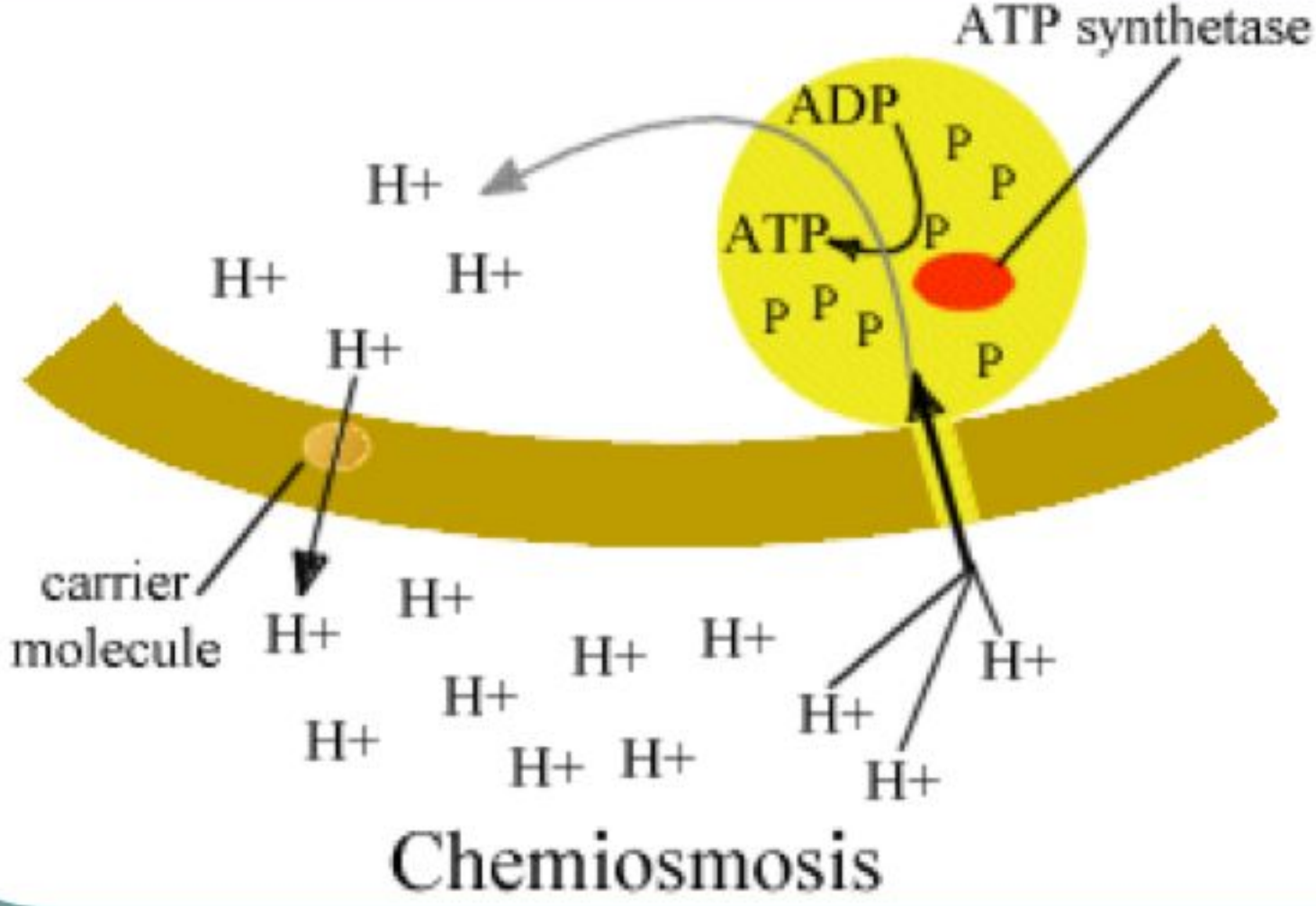

An animal cell
Mitochondrion
Matrix
Inner membrane
Intermembrane space
Outer mitochondrial membrane
OXIDATIVE PHOSPHORYLATION
Electron transport and oxidative phosphorylation are carried out by proteins on the inner mitochondrial membrane.
Intermembrane space
Inner mitochondrial membrane
Mitochondrial matrix
NADH
NAD+
+H+
H2O
O2
ADP
+Pi
ATP
Electron transport (the respiratory chain)
ATP production

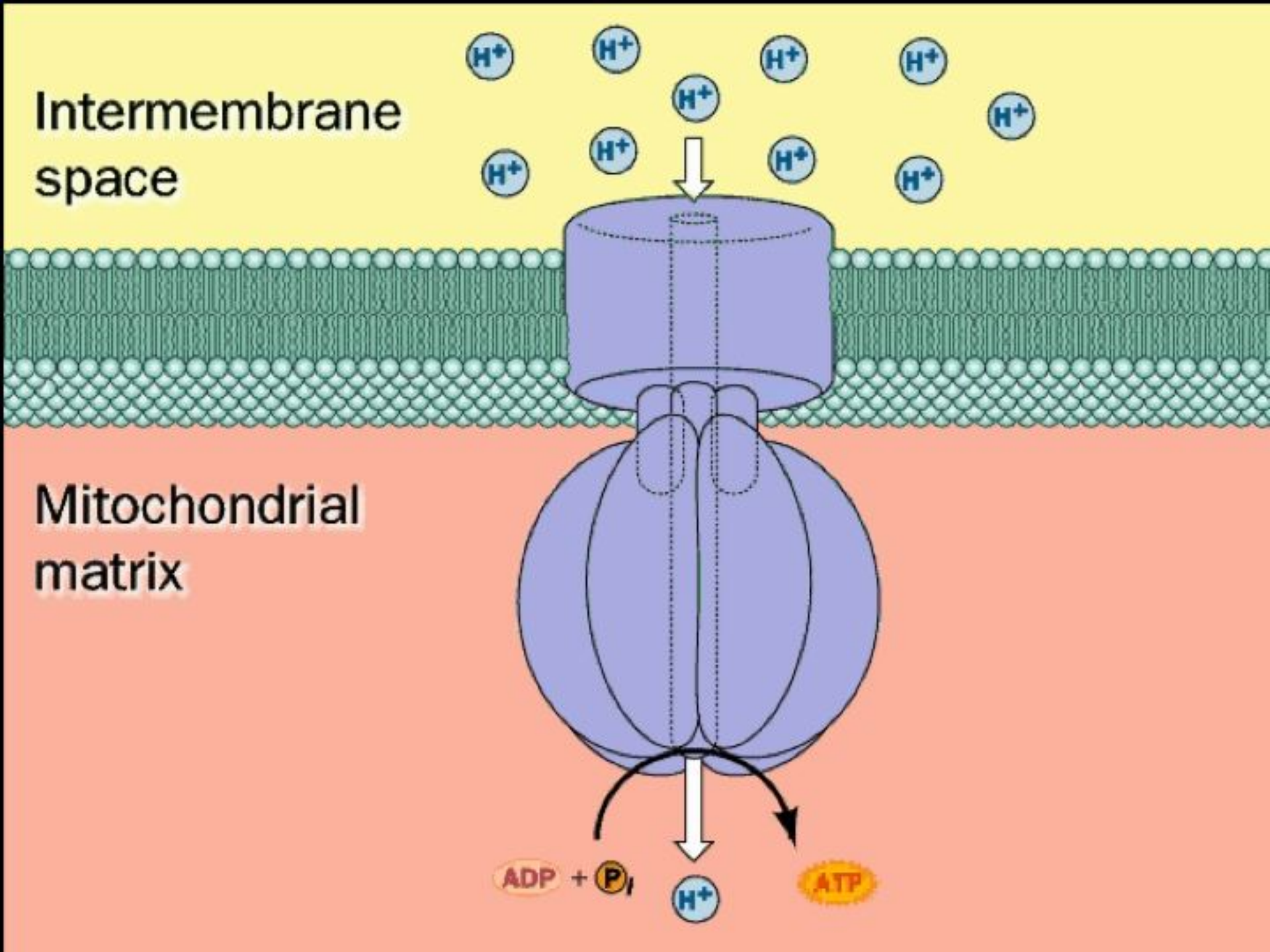


Chemiosmosis

- Describes how ATP is actually generated
- Special carrier molecules use the energy released in the electron transport chain to bring hydrogen atoms close to the membrane and separate the hydrogen into an H+ ions and electrons.
- The electrons are brought back to the inside of the membrane while the H+ ions are forced to the other side.
- As more and more H+ ions accumulate on the outside of the membrane, two gradients are formed.
  - First, a pH gradient is formed. This means that the outside is more acidic (because it has H+ ions) than the inside of the membrane.
  - Also, an electrical gradient forms, since H+ ions have a positive charge.
- When these gradients become sufficiently intense, they force the H+ ions through a channel in the membrane in a tremendous gush.
- As the H+ ions rush by, they provide the energy which brings the ATP synthetase, ADP, and phosphates together. The ATP synthetase bonds the ADP and phosphate molecules, forming ATP.
- The H+ ions, now on the inside of the membrane, can be transported by the carrier molecules across the membrane so that the process may be repeated when enough energy is released from the electron transport chain.

Chemiosmosis




Intermembrane space
Mitochondrial matrix
H+
ADP + Pi
ATP

Energy yield from Aerobic Cellular Respiration