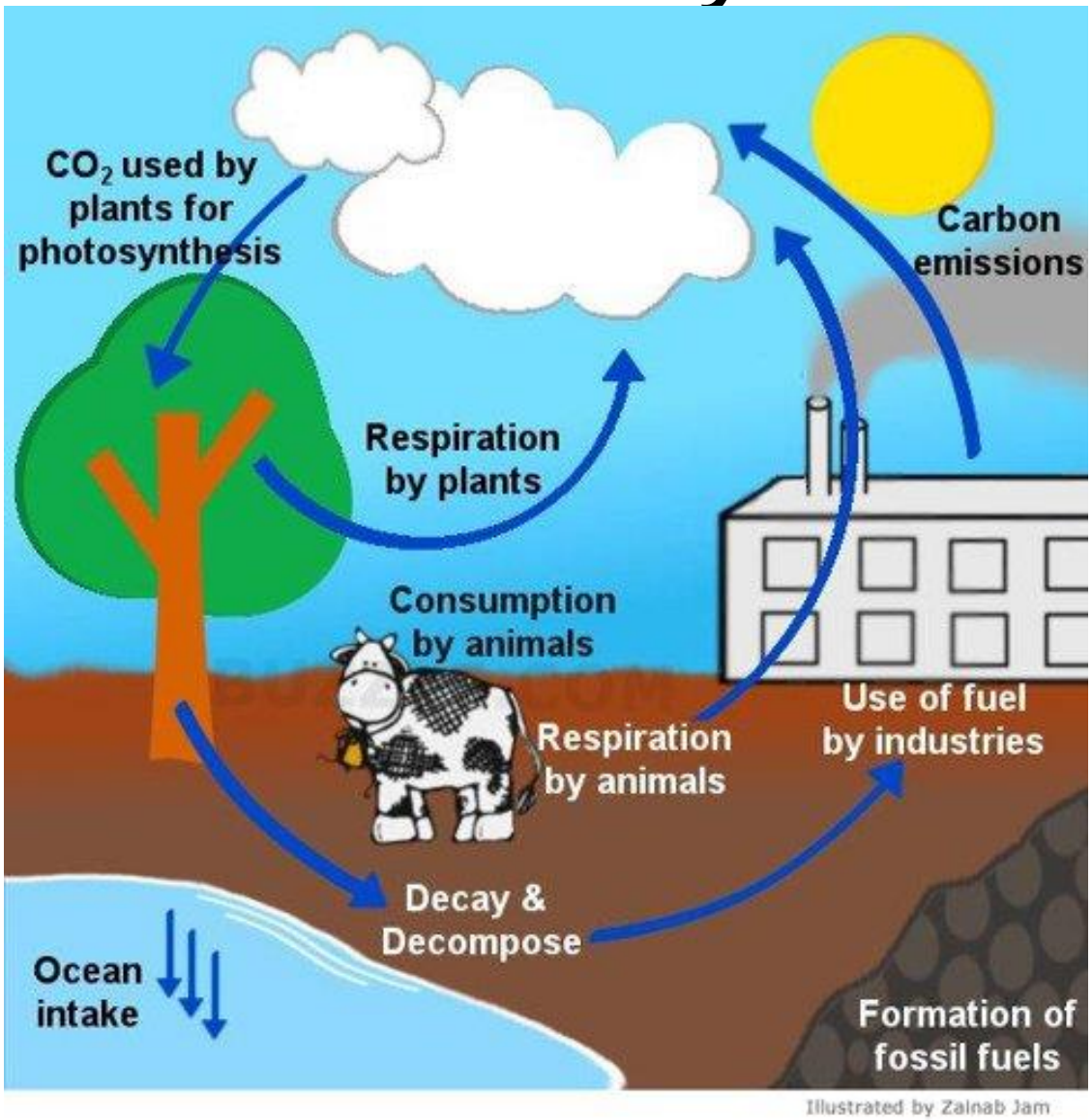
Cell Energetics

How plants make food and everyone makes energy!

Carbon Cycle



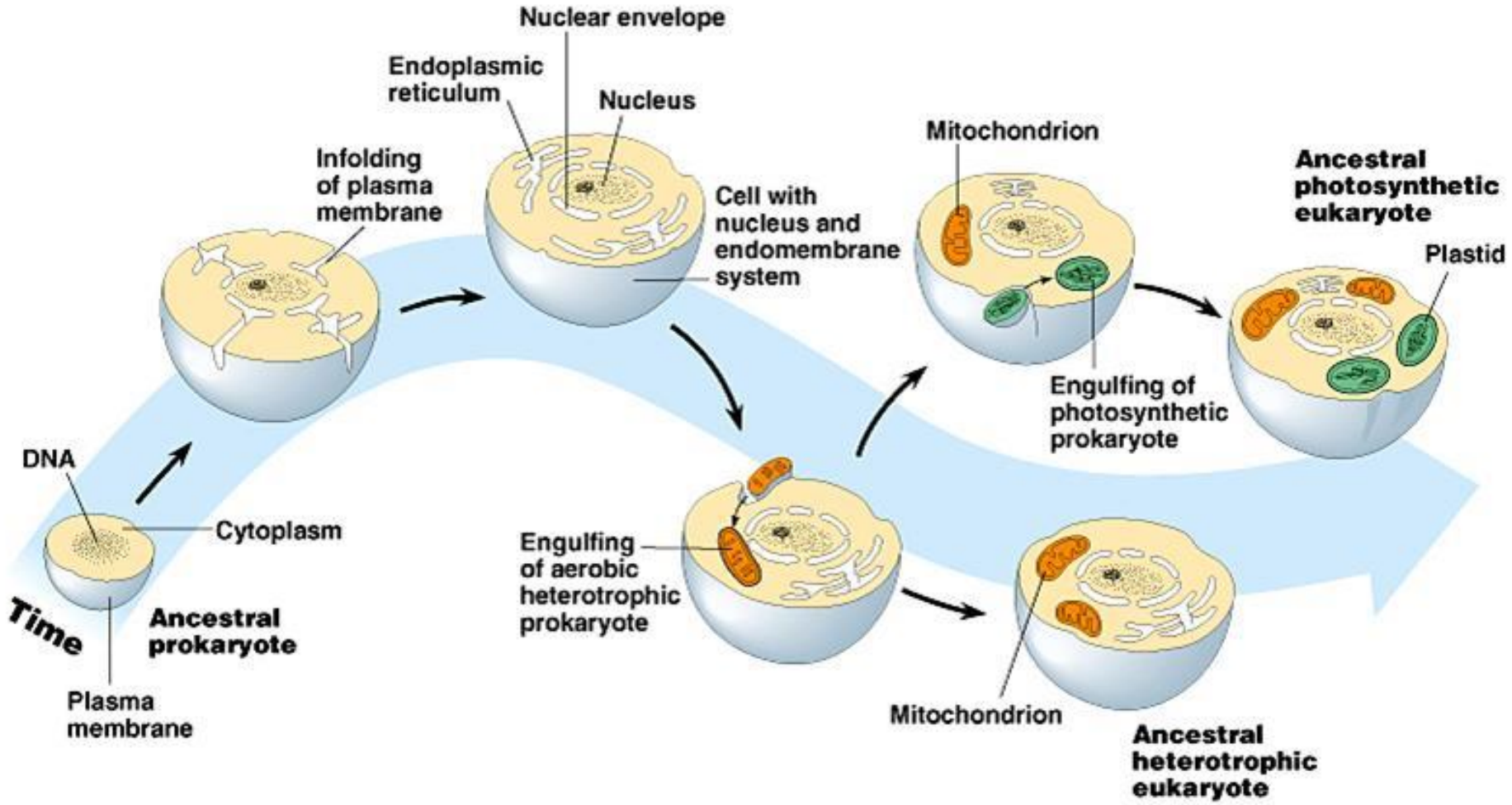
Where did the mitochondria and chloroplast come from?

Endosymbiotic Theory

- Endosymbiotic theory = a theory that some of the cell's organelles descended from prokaryotic cells (bacteria)
  - Bacteria was consumed by another bacteria and came to live within the cell
  - Chloroplasts and mitochondria are the organelles once thought to be free living bacteria

Evidence to Support This Theory

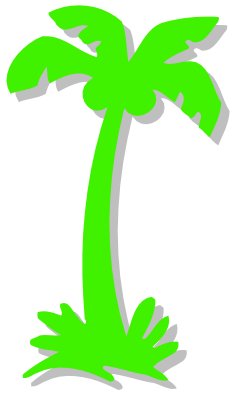
- Both organelles have DNA
- Both contains ribosomes that make proteins
- Both can multiply by itself



Light Energy

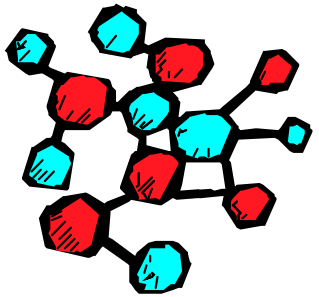
Mechanical Energy (ATP)

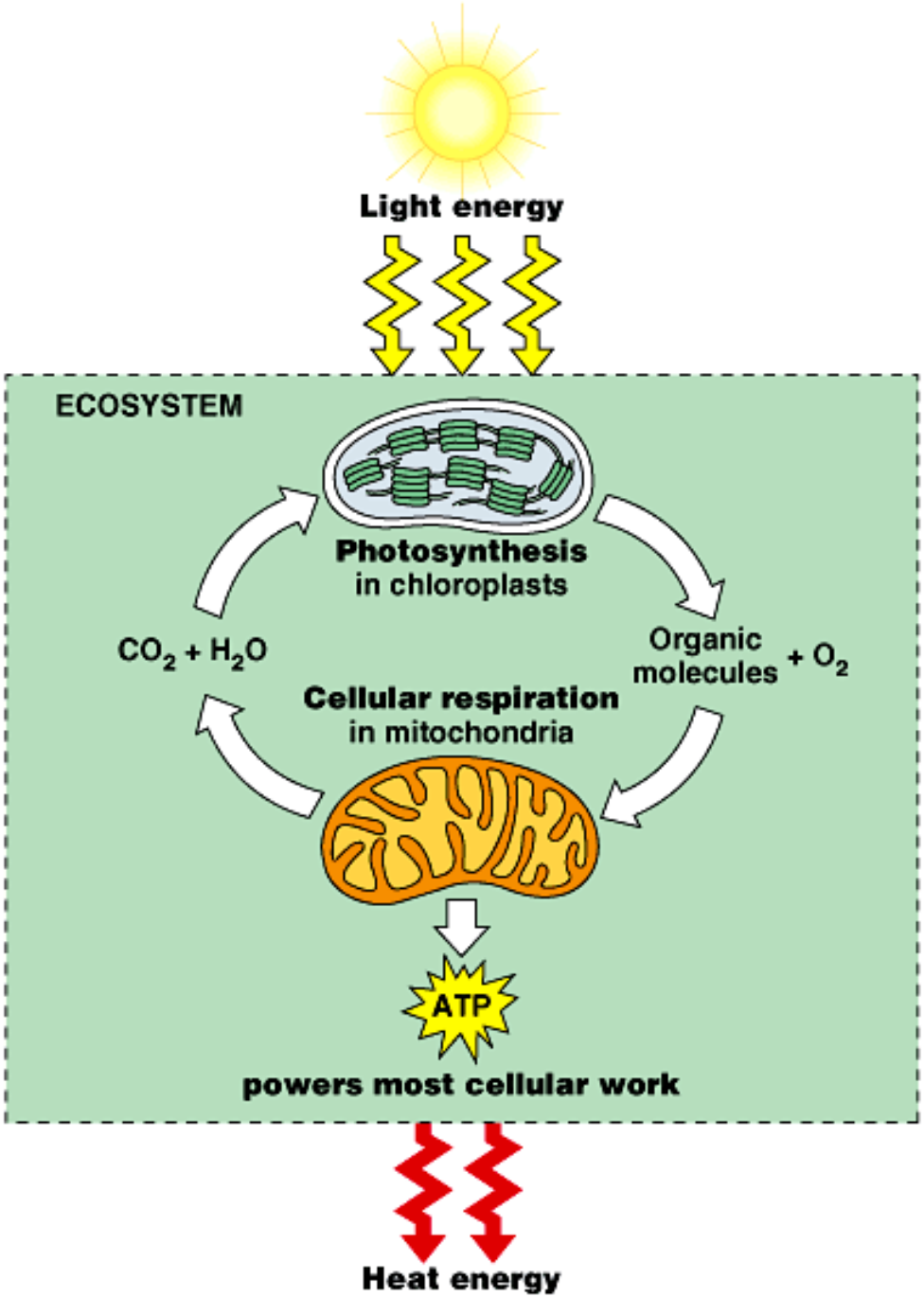
Photosynthesis



Chemical Energy

Glucose





The Basics

Photosynthesis

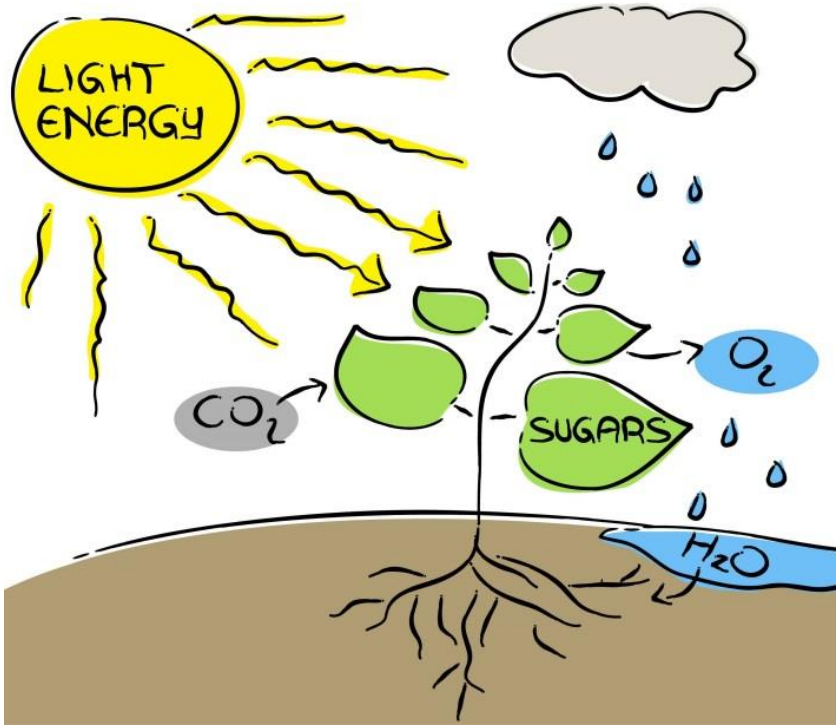
- Definition: The process by which autotrophs use light energy to convert, carbon dioxide and water into carbohydrates

- Occurs in the chloroplast
- Occurs only in plants, some protists (algae), and some bacteria

Equation

$CO_2 + H_2O + \text{Light energy} \rightarrow \text{Glucose} + O_2$

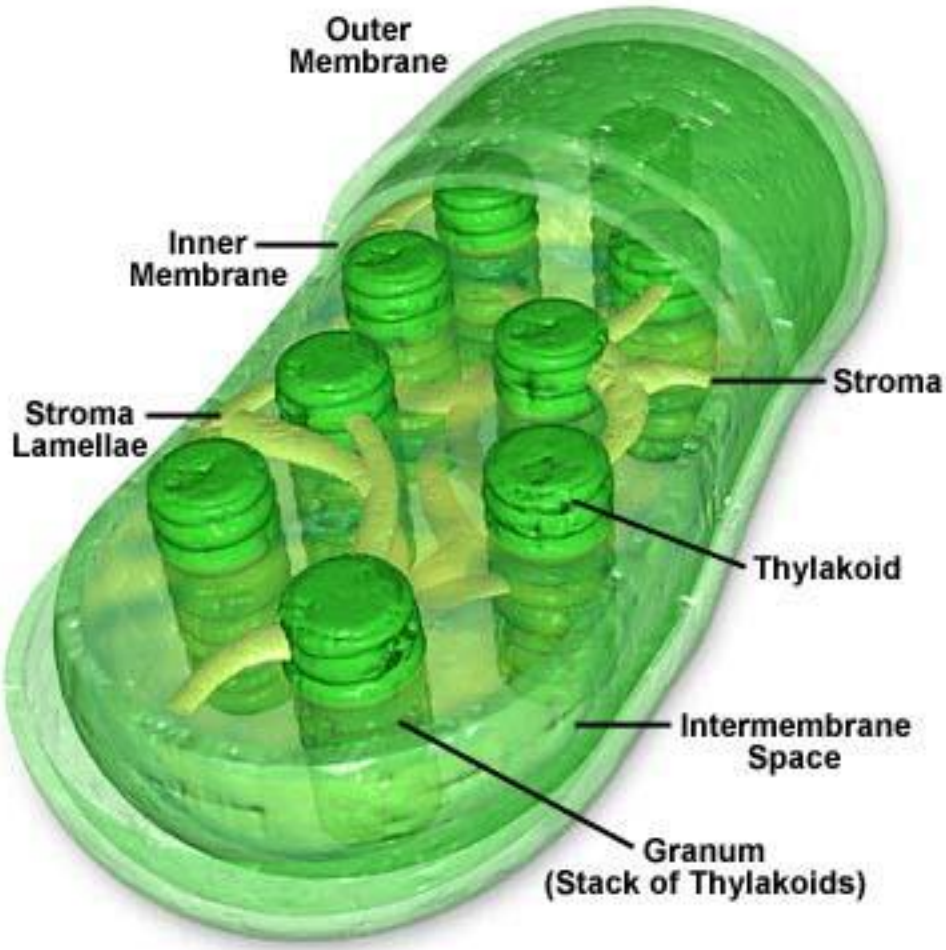
$C_6H_{12}O_6$



Photosynthesis

- 2 parts

- Light reaction = thylakoid (disk)
- Calvin cycle = stroma (fluid)



Cell Respiration

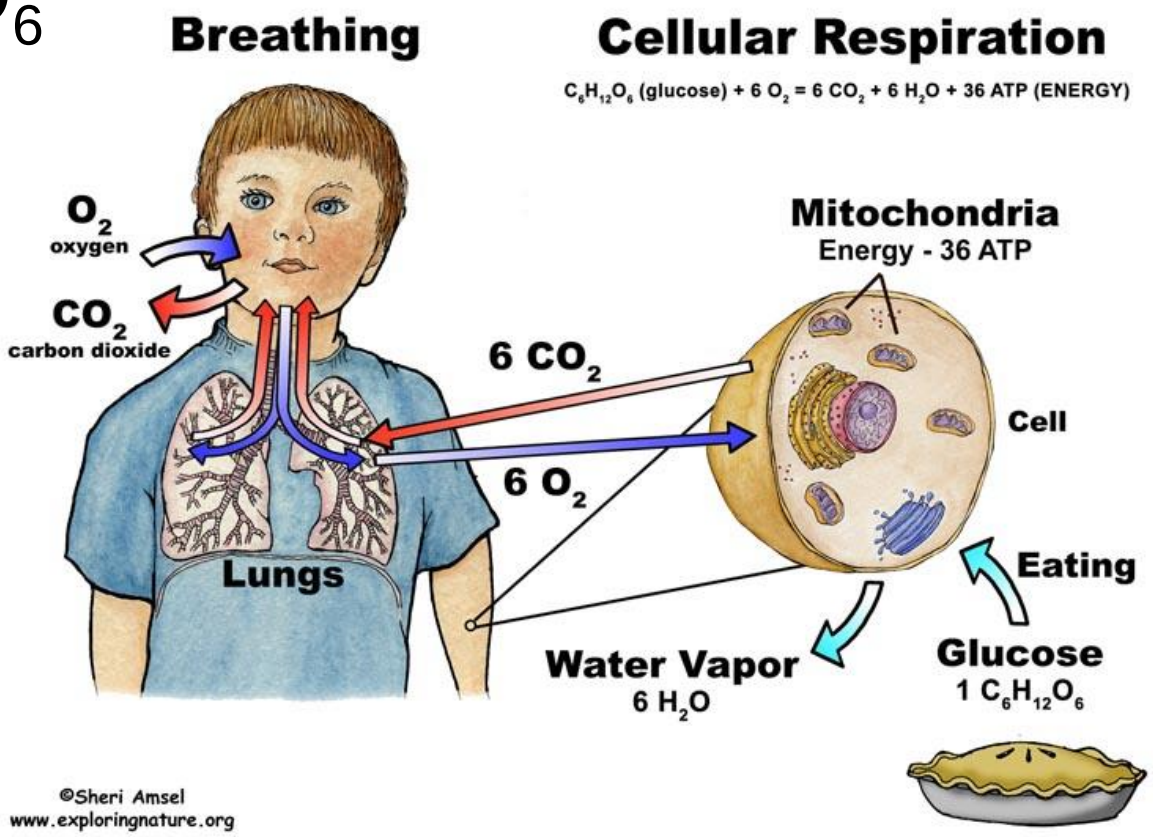
- Definition: The process by which cells produce energy (ATP) from carbohydrates

- Occurs in mitochondria
- Occurs in both autotrophs and heterotrophs (all eukaryotic organisms)

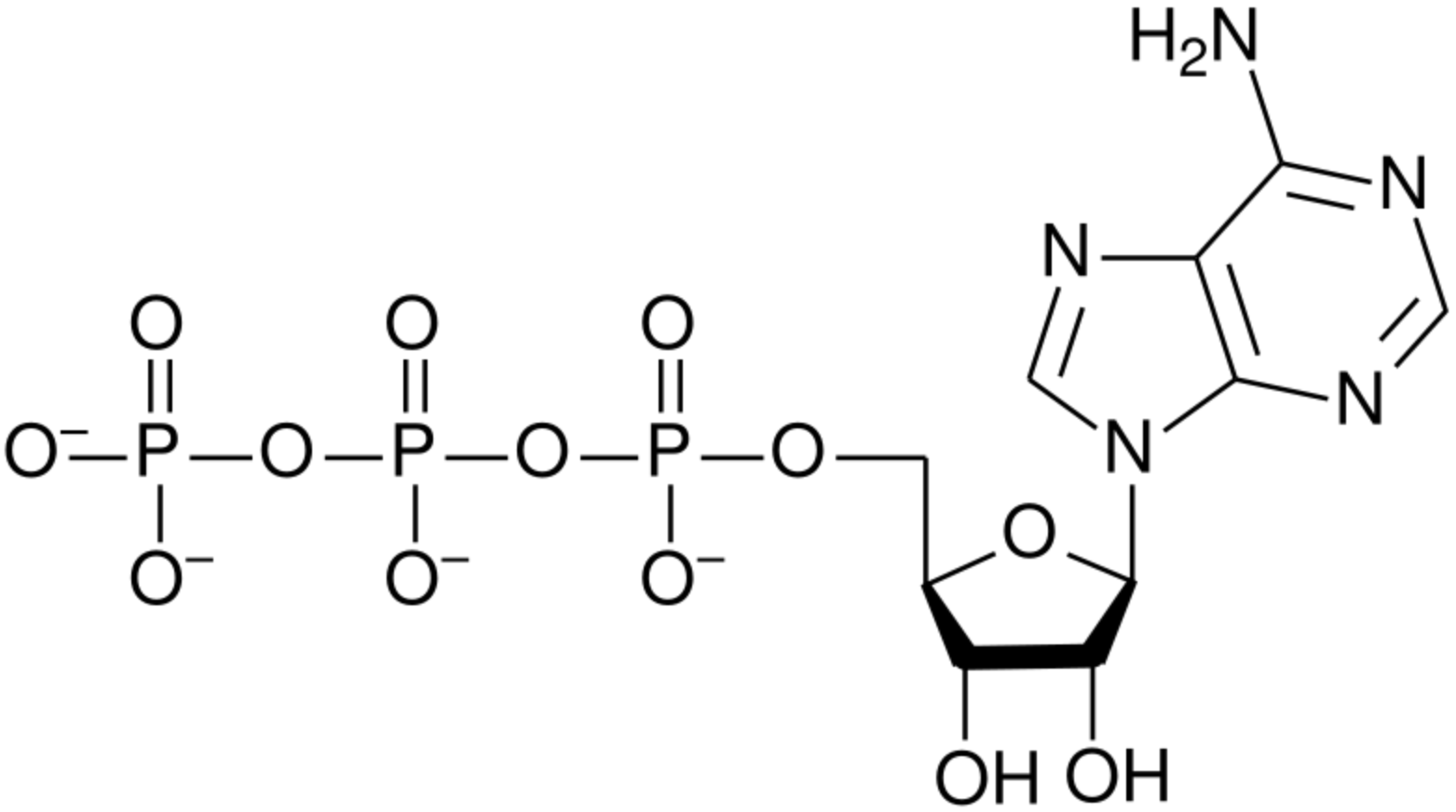
Equation

- Glucose + O_2 → CO_2 + H_2O + energy (ATP)

  $C_6H_{12}O_6$



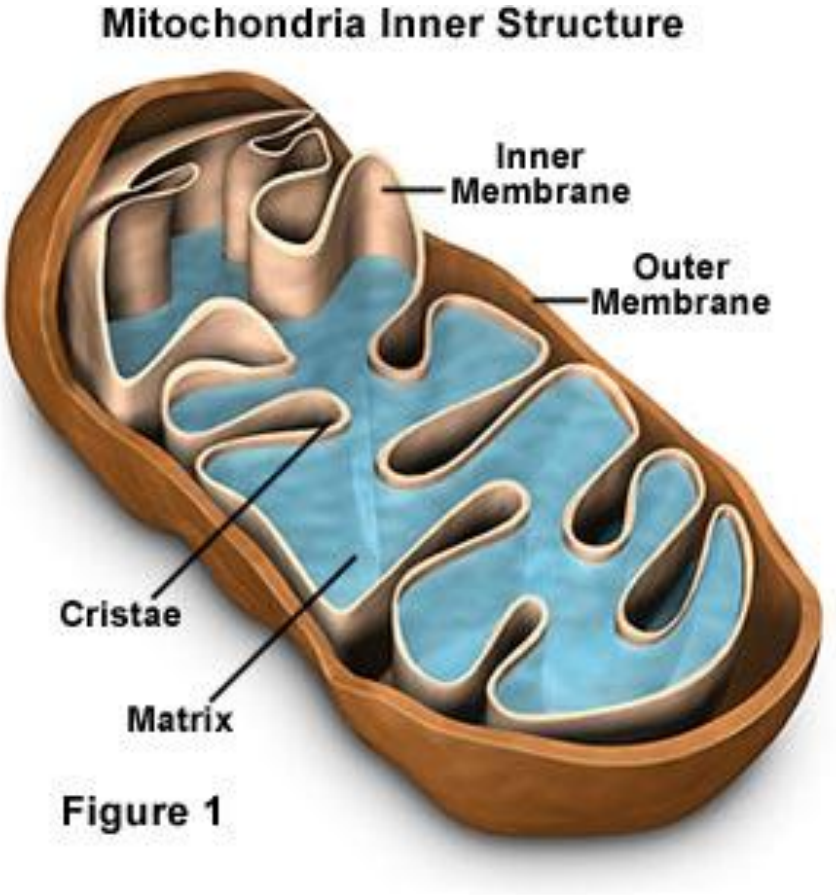
ATP = Adenosine Triphosphate



Cell Respiration

- 3 parts

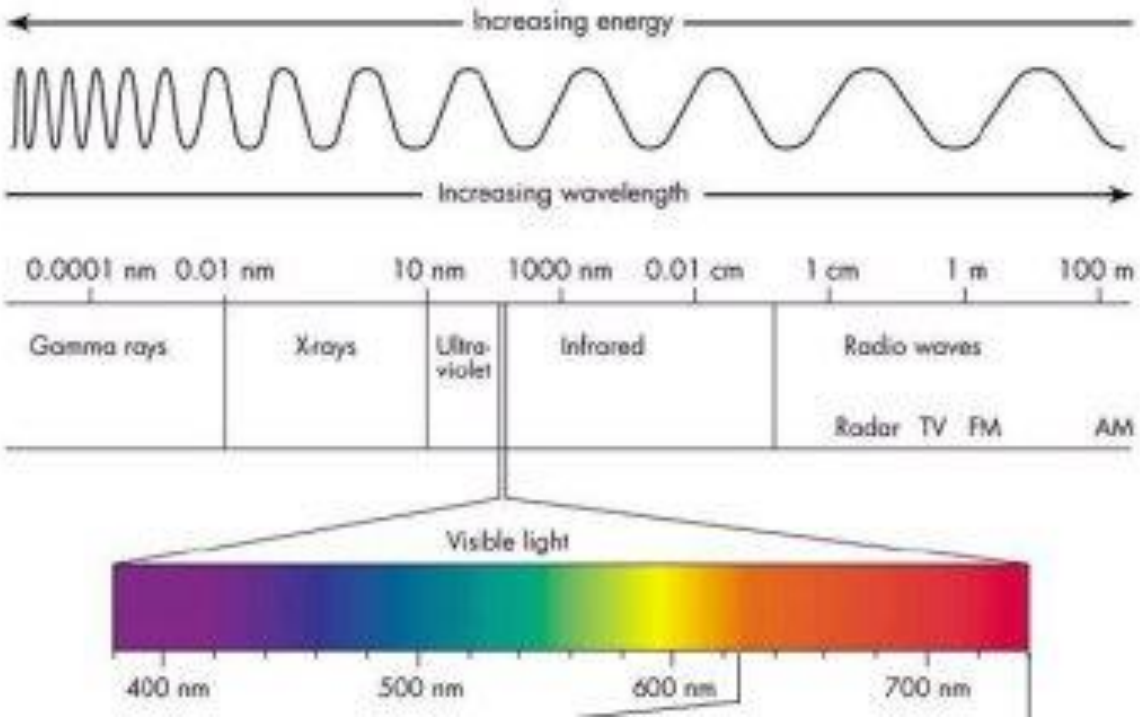
- Glycolysis = cytoplasm
- Krebs Cycle = matrix of mitochondria
- Electron Transport Chain = inner membrane of mitochondria
  - Inner membrane = cristae



Photosynthesis: The Details

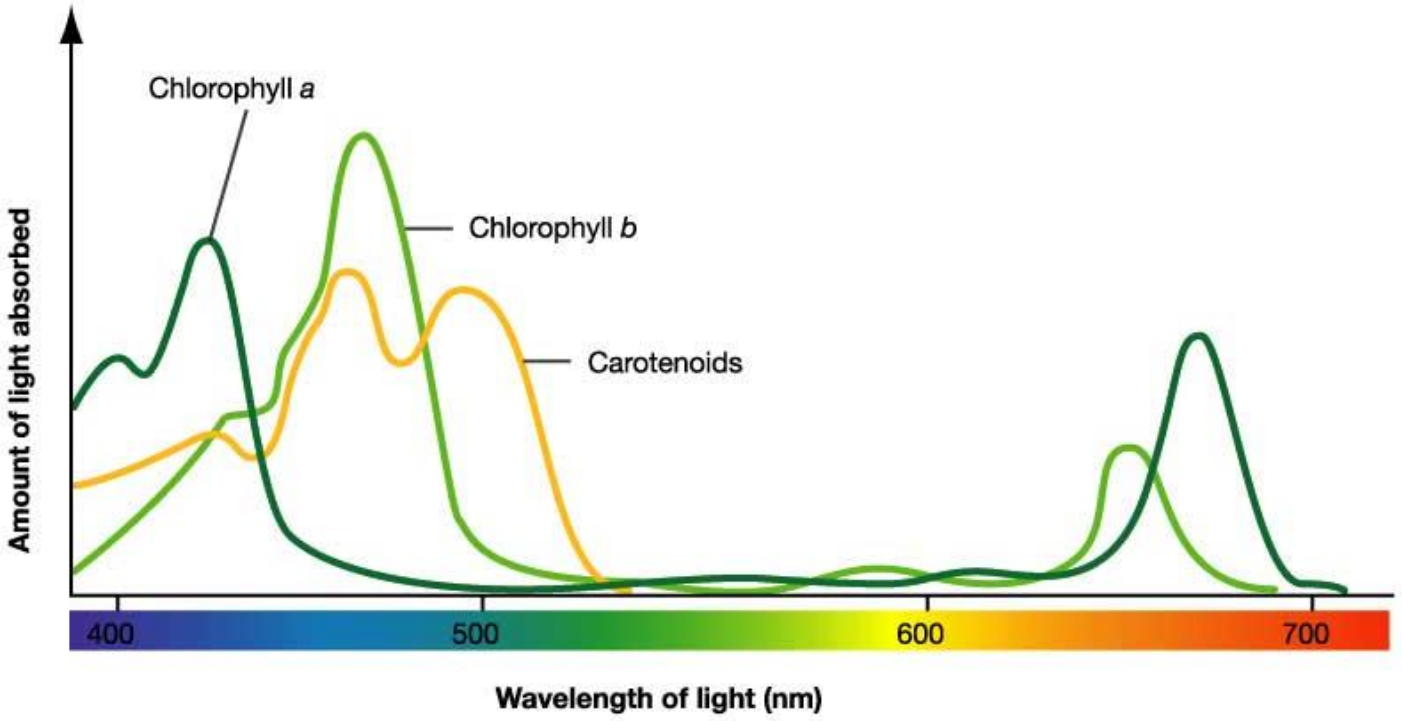
Light

- Different wavelengths make up the light we see
- If we see green, then the green wavelength is being reflected back at us



Pigments in Plants

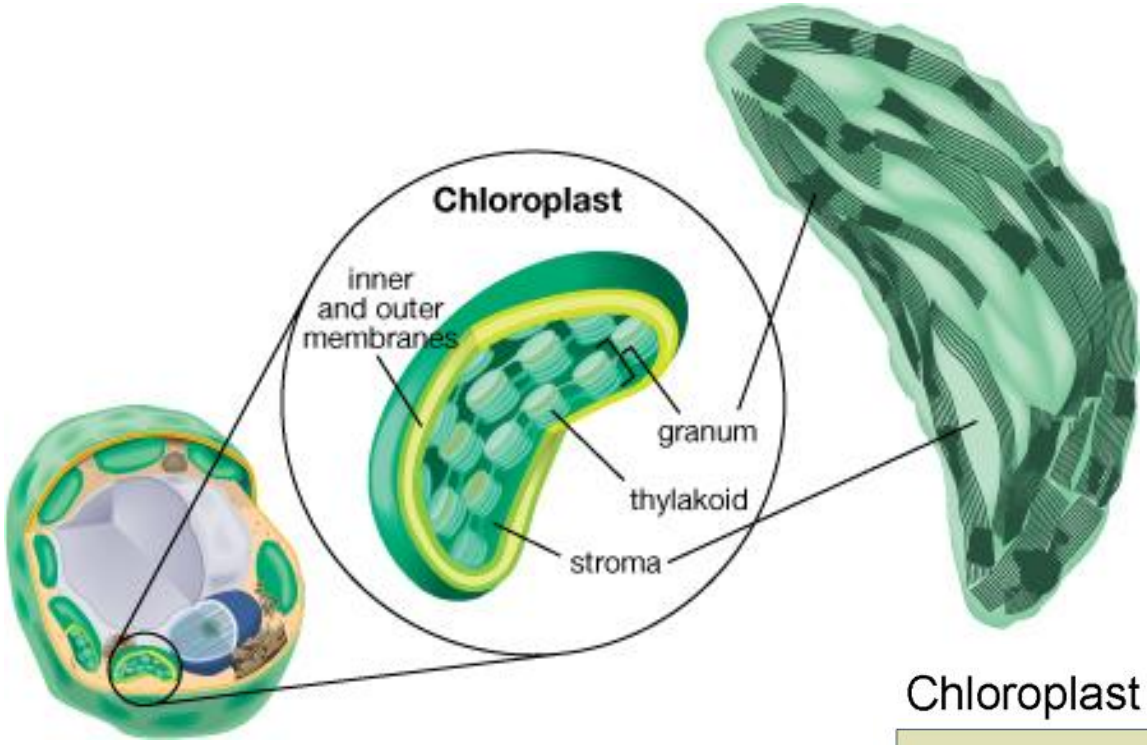
- Multiple pigments in plants are used to capture the light wavelengths, but *chlorophyll a* is the main pigment



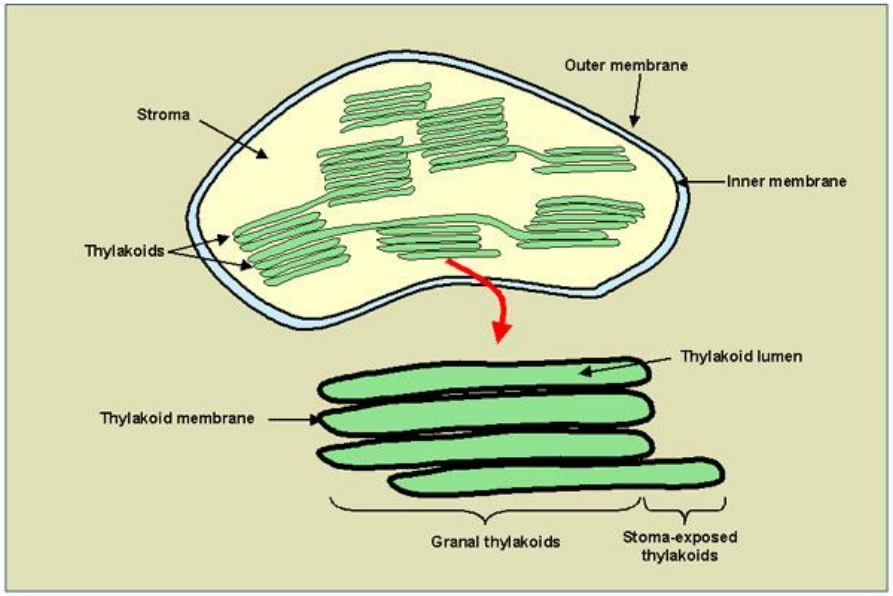
Light Reaction

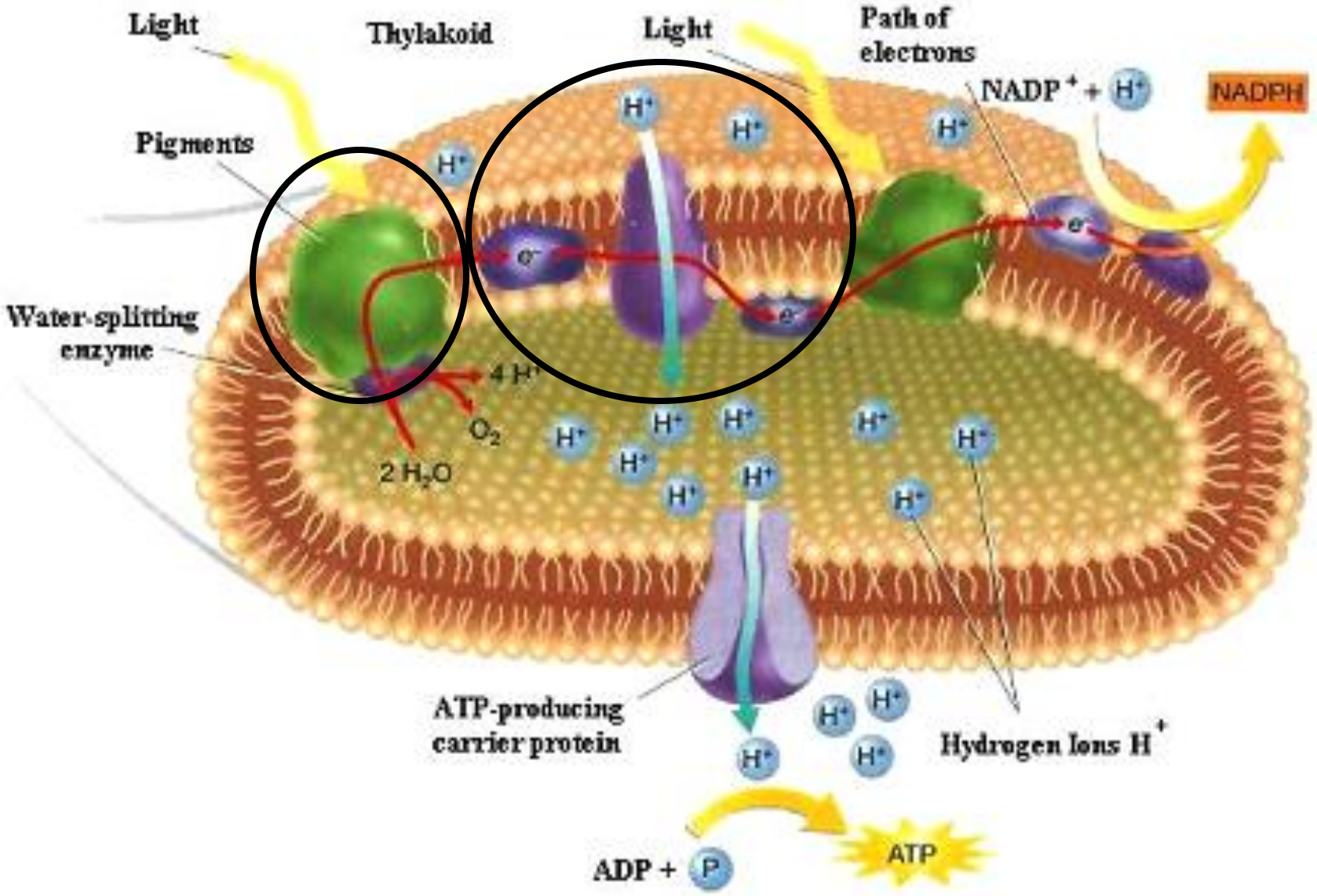
- A photon of light hits the chlorophyll (pigment) located in Photosystem II
  - Photosystem II is embedded in the thylakoid membrane

- An electron from the chlorophyll gets excited by the light and moves out of Photosystem II along a series of proteins (electron transport chain) in the membrane
  - This powers the movement of H+ into the disk



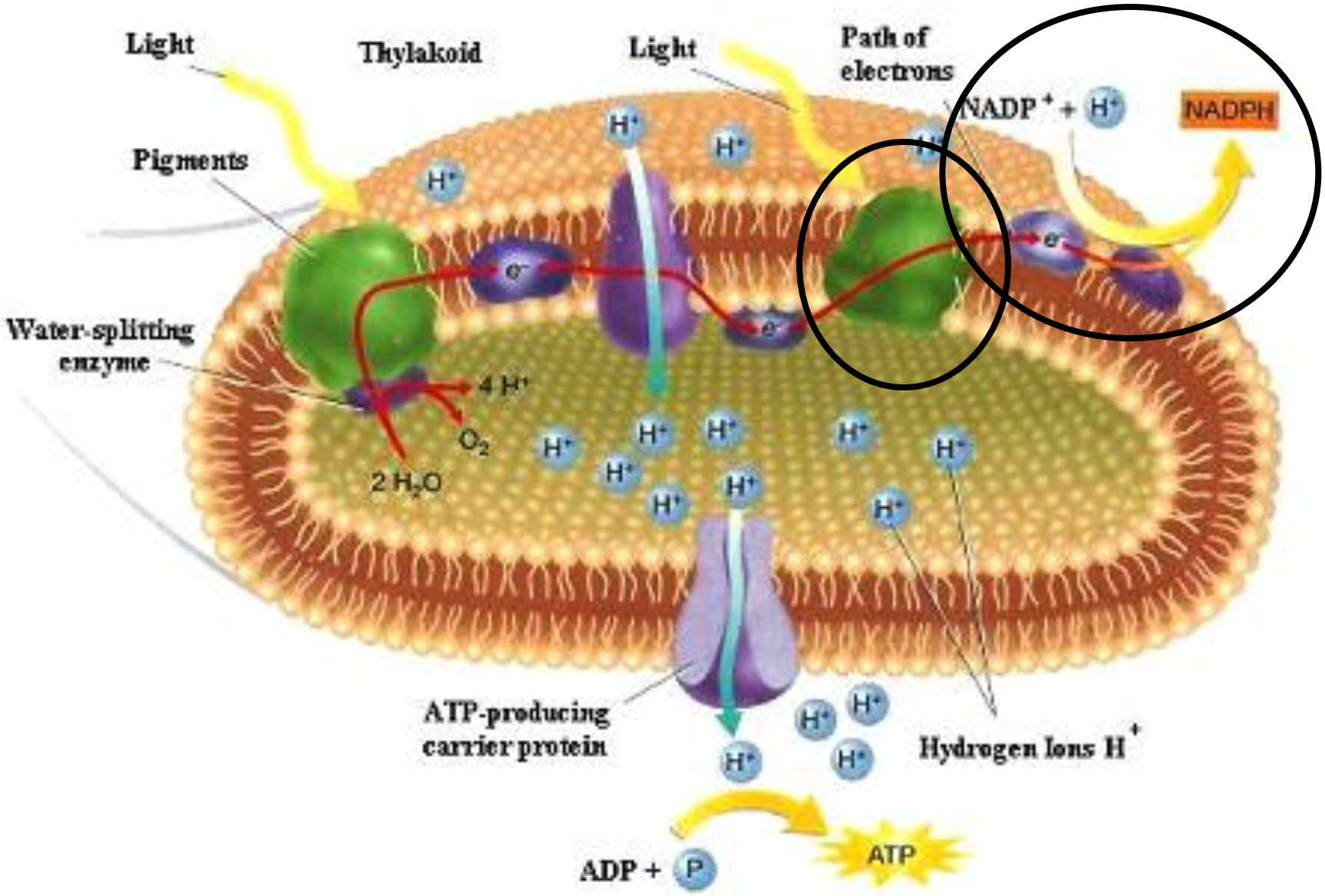
Chloroplast




Light
Thylakoid
Light
Path of electrons
NADP+ + H+
NADPH
Pigments
Water-splitting enzyme
4 H+
O2
2 H2O
ATP-producing carrier protein
Hydrogen Ions H+
ADP + P
ATP

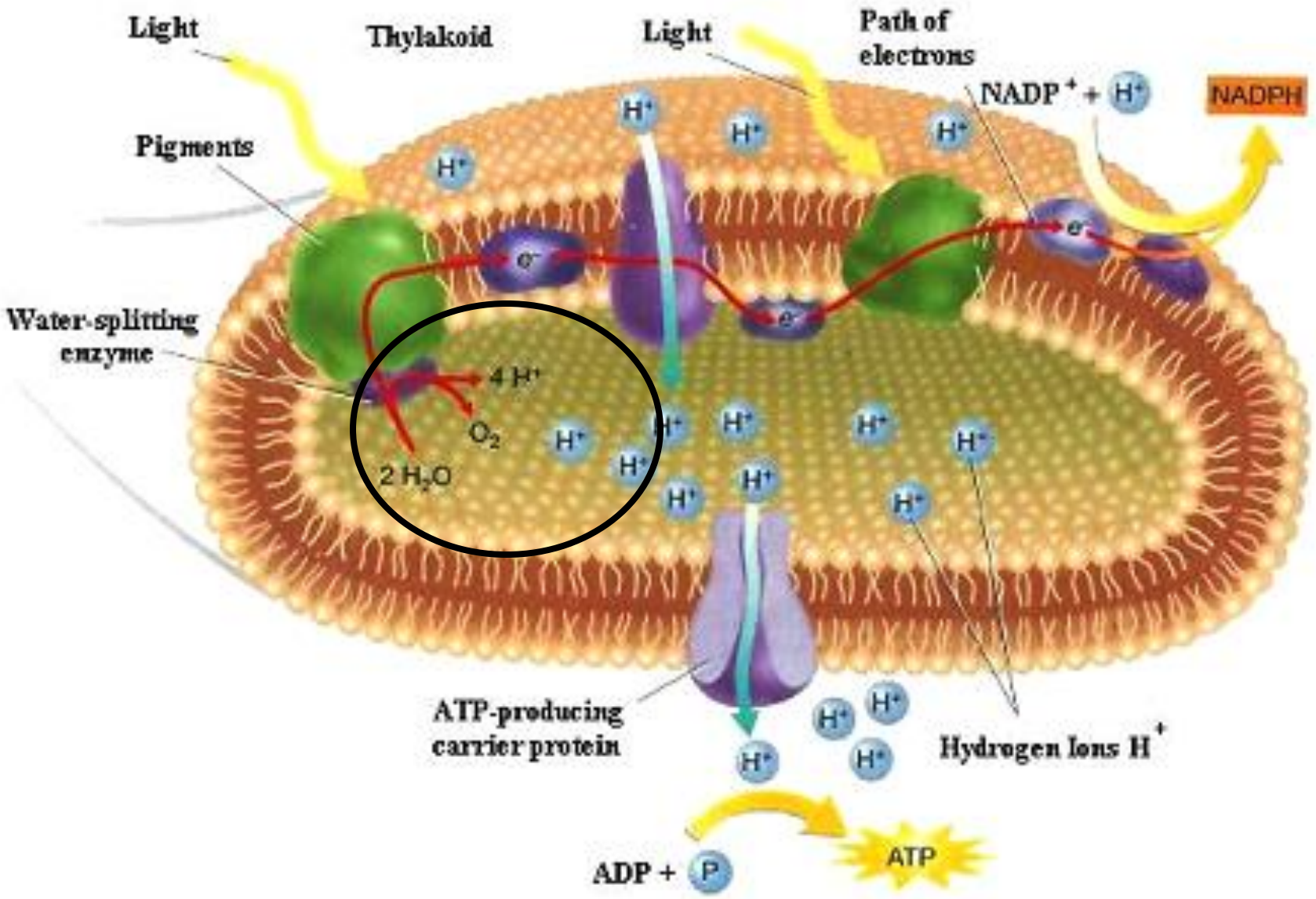
Light Reaction

- Another photon of light hits another group of chlorophyll in Photosystem I also in the membrane
- The same electron gets excited again
- The electron is used to make a carrier molecule called NADPH


Light
Thylakoid
Light
Path of electrons
NADP+ + H+
NADPH
Pigments
Water-splitting enzyme
4 H+
O2
2 H2O
ATP-producing carrier protein
Hydrogen Ions H+
ADP + P
ATP

Light Reaction

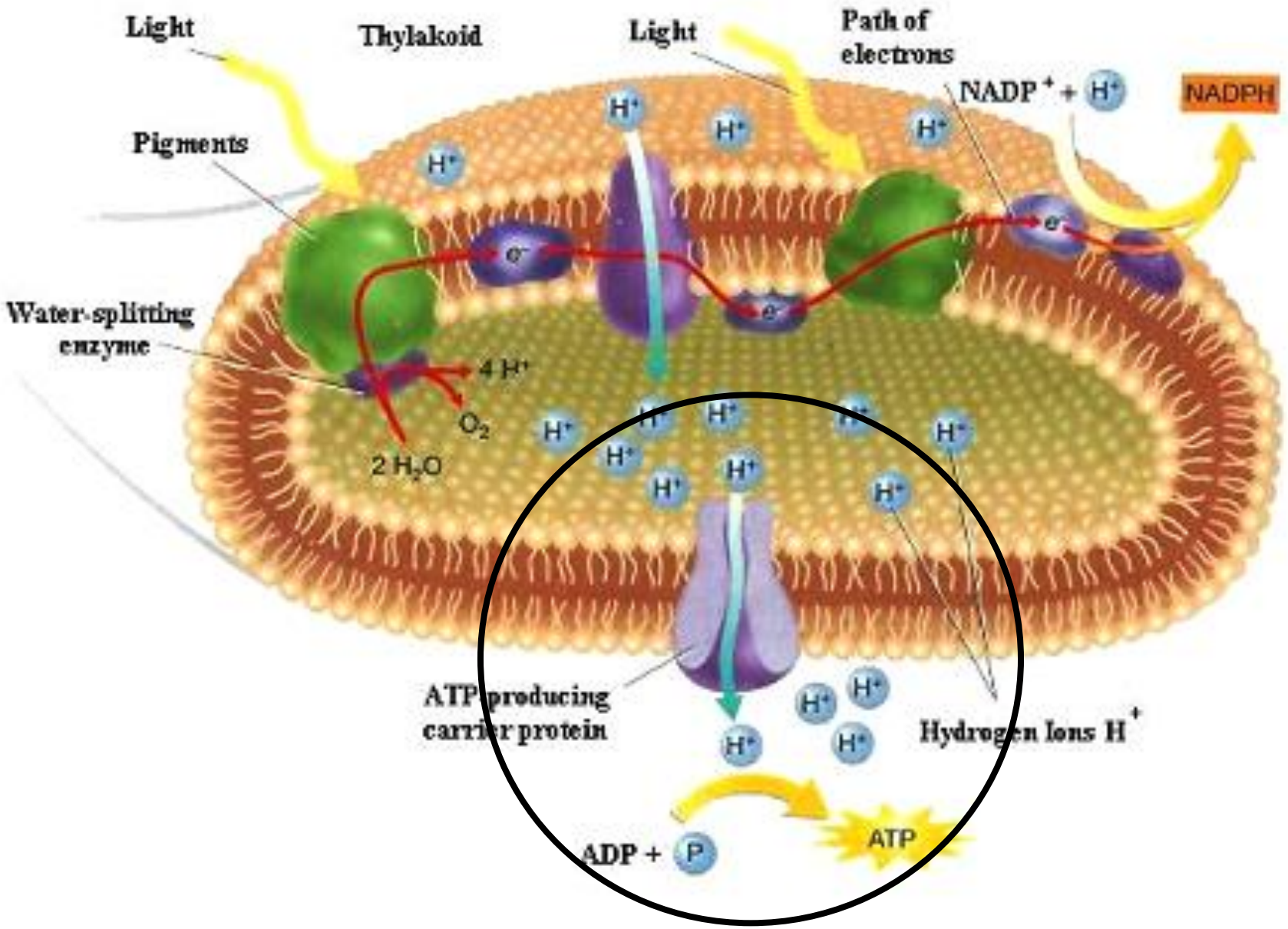
- The lost electron gets replaced when a water molecule splits into oxygen and hydrogen within the disk
  - Oxygen (O_2) leaves the plant and H+ gets added to the growing concentration inside the disk

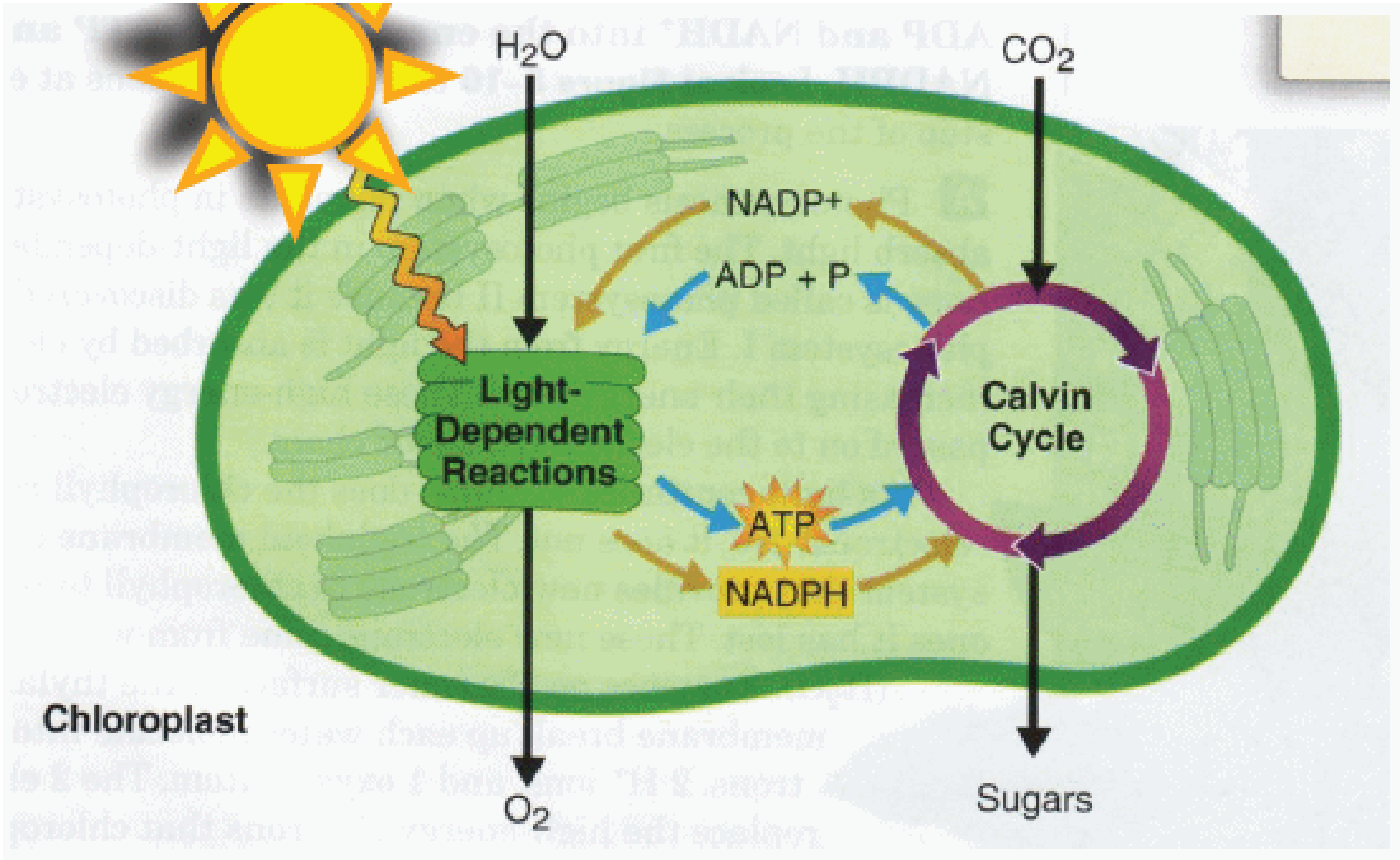

Light
Thylakoid
Light
Path of electrons
NADP+ + H+
NADPH
Pigments
Water-splitting enzyme
4 H+
O2
2 H2O
ATP-producing carrier protein
Hydrogen Ions H+
ADP + P
ATP

Light Reaction

- Then, ATP is built when the build up of H+ in the thylakoid causes them to move out through a special protein – ATP synthase
  - This is an enzyme in the thylakoid membrane
- ATP synthase causes a P to get added to ADP to create ATP

- End Result: NADPH and ATP…O_2 leaves the cell and then the plant


Light
Thylakoid
Light
Path of electrons
NADP+ + H+
NADPH
Pigments
Water-splitting enzyme
4 H+
O2
2 H2O
ATP-producing carrier protein
Hydrogen Ions H+
ADP + P
ATP


H_2O
CO_2
NADP+
ADP + P
Light-Dependent Reactions
Calvin Cycle
ATP
NADPH
Chloroplast
O_2
Sugars

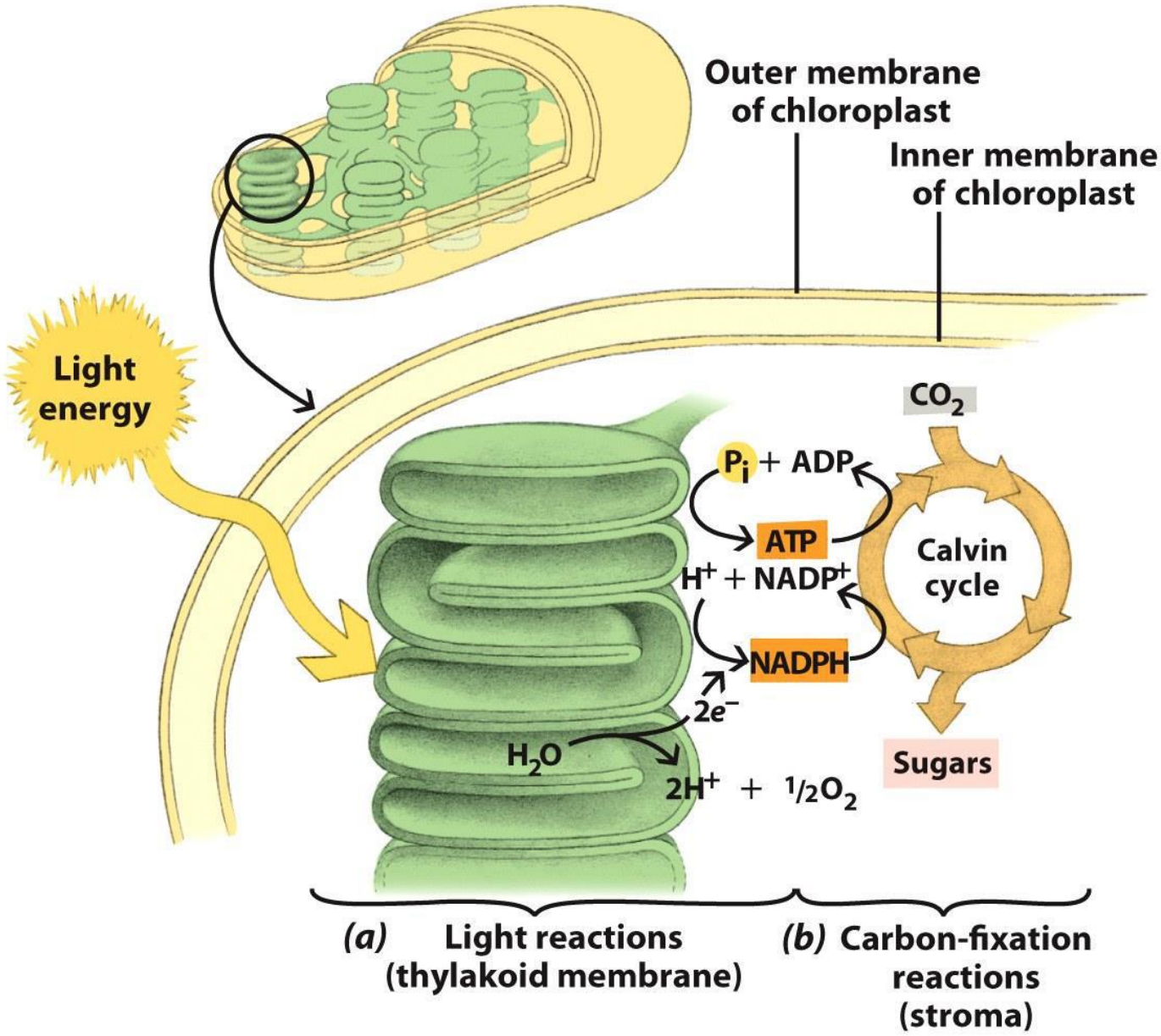
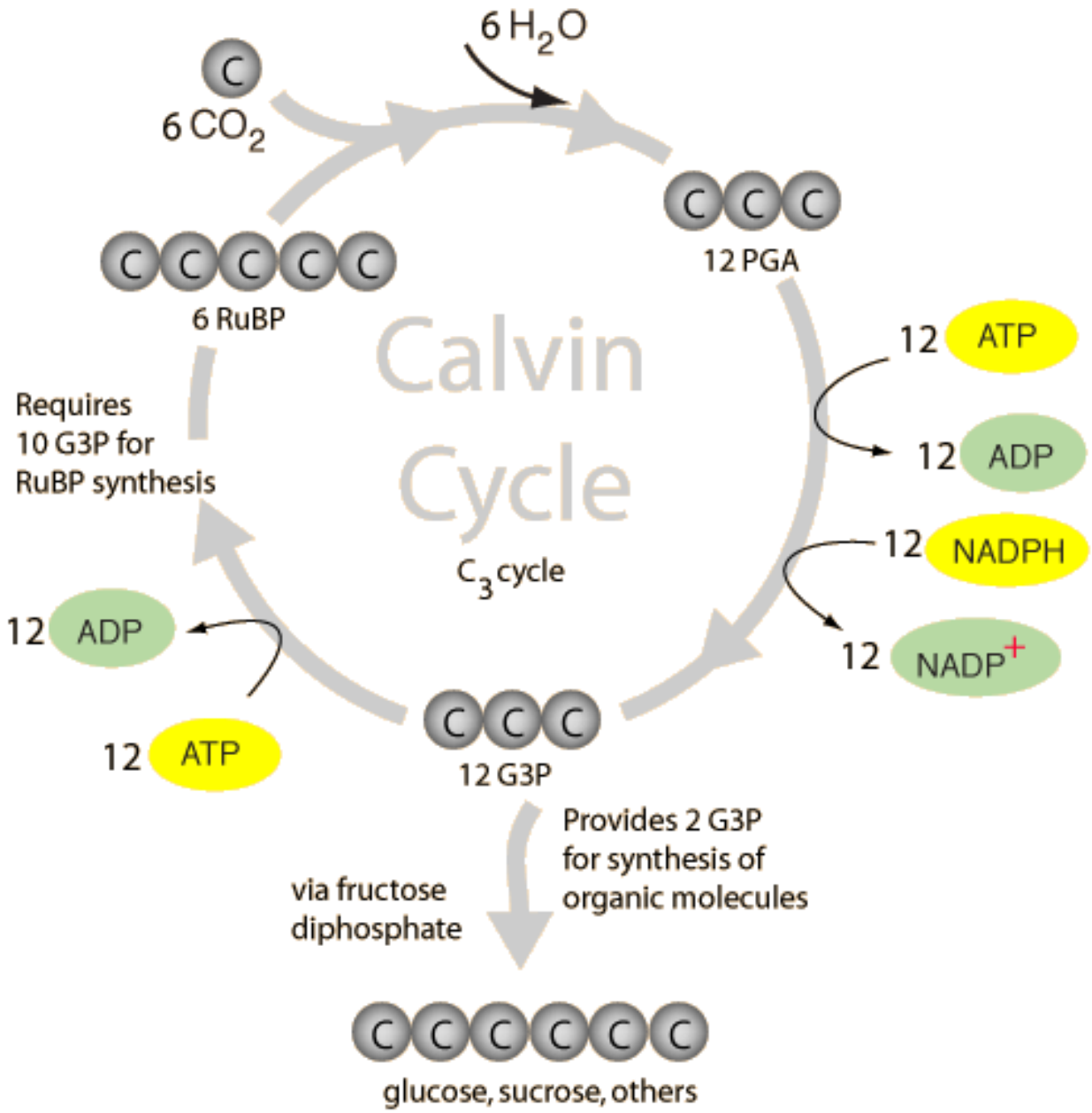


Figure 7-9
***Raven Biology of Plants*, Eighth Edition**

Calvin Cycle

- NADPH and ATP move to the stroma to be used in the next series of steps

- CO_2 comes into the cell and into the chloroplast and attaches to a 5-carbon molecule (RuBP) that is already in the organelle by an enzyme called Rubisco

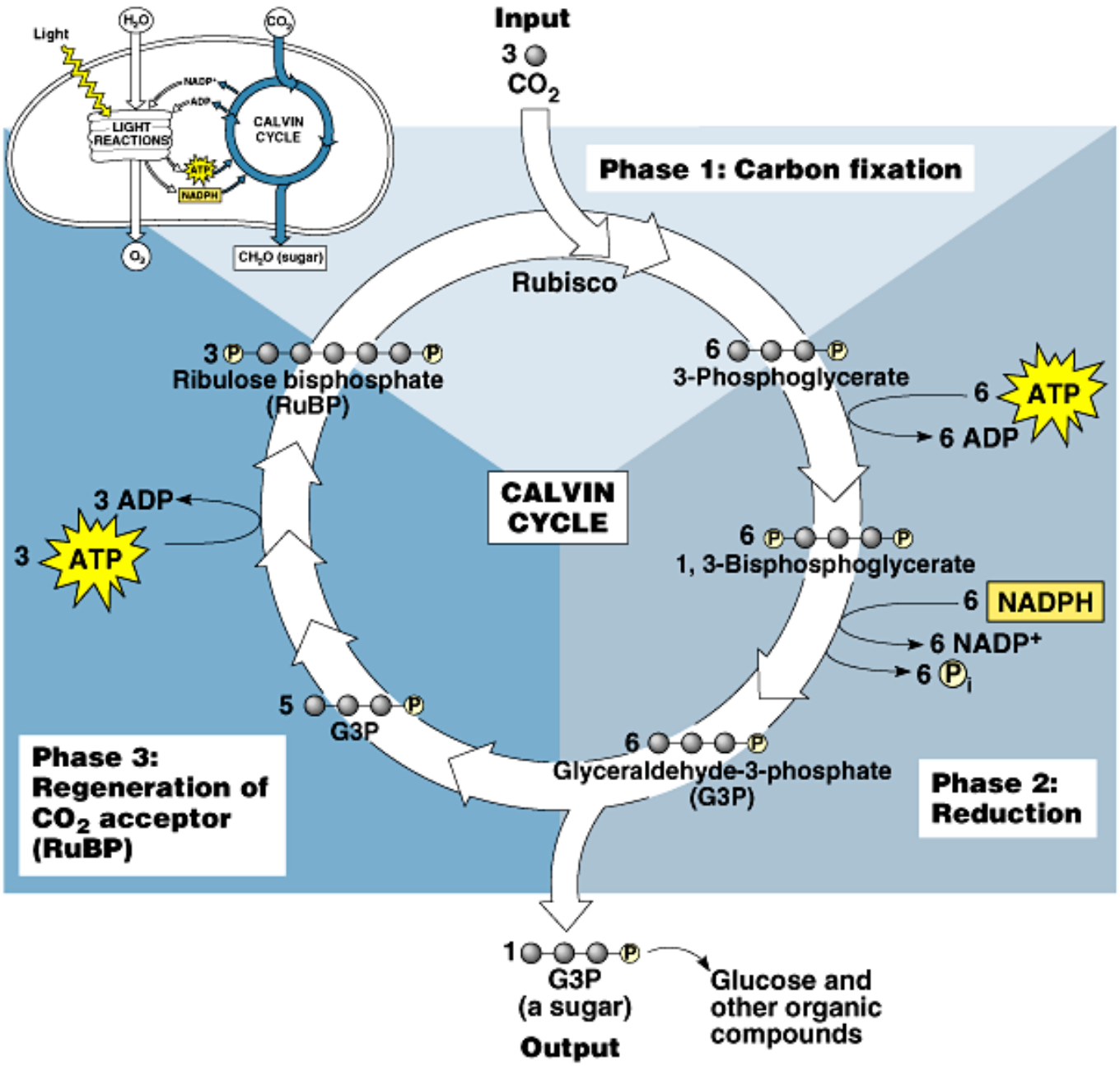

6 H_2O
C
6 CO_2
C C C
12 PGA
12 ATP
12 ADP
12 NADPH
12 $NADP^+$
C C C C C
6 RuBP
Calvin Cycle
C_3 cycle
Requires 10 G3P for RuBP synthesis
12 ADP
12 ATP
C C C
12 G3P
Provides 2 G3P for synthesis of organic molecules
via fructose diphosphate
C C C C C C
glucose, sucrose, others

Calvin Cycle

- This new 6-carbon molecule goes through a series of changes using the release of energy from ATP and the stored electrons from the NADPH

Calvin Cycle

- The electrons allow new bonds to form and energy is needed to build 1 sugar and the rest of the elements reform the original 5-carbon molecule
  - The sugar made is G3P which later makes glucose



Factors affecting photosynthesis

- **Light intensity / amount –** the more light or the higher the intensity, the more photosynthesis will occur
- **Temperature –** increase will denature enzymes in the reaction, reducing photosynthesis
- **Amount of CO_2 available –** increase in a reactant will increase photosynthesis products

Videos

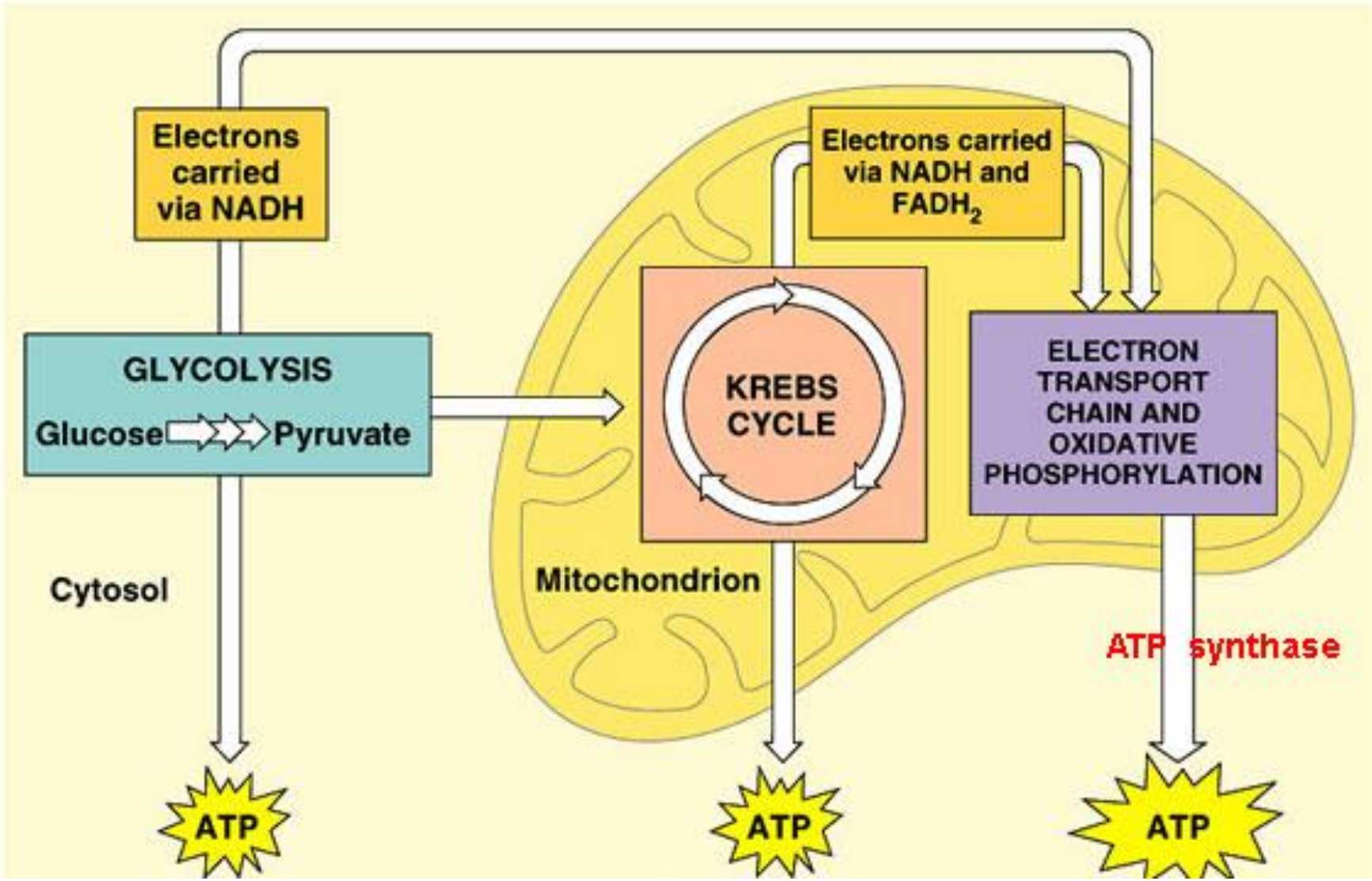
- Endosymbiotic Theory
- Light reaction
- Calvin cycle
- Amoeba sisters photosynthesis

Lab Simulations

- Elodea Leaf

Cellular Respiration: The Details

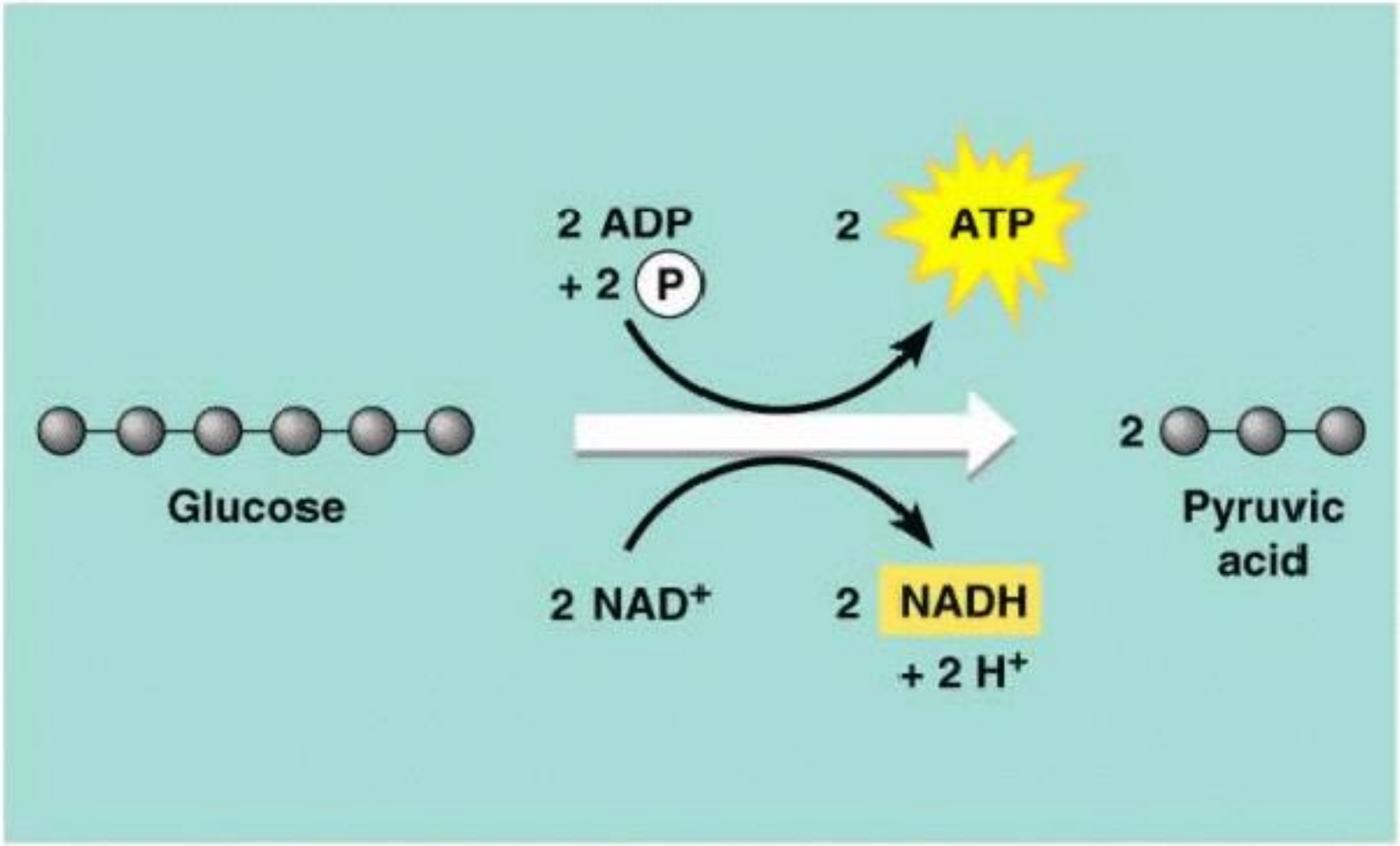
Cell Respiration



Step 1: Glycolysis

- Glucose comes into the cell and is too big to fit into the mitochondria
- Glucose (6-C) is broken down into two 3 carbon molecules called pyruvic acid and a carrier molecule is formed
  - This occurs in the cytoplasm

- End Results of this step: **2 ATP** and NADH

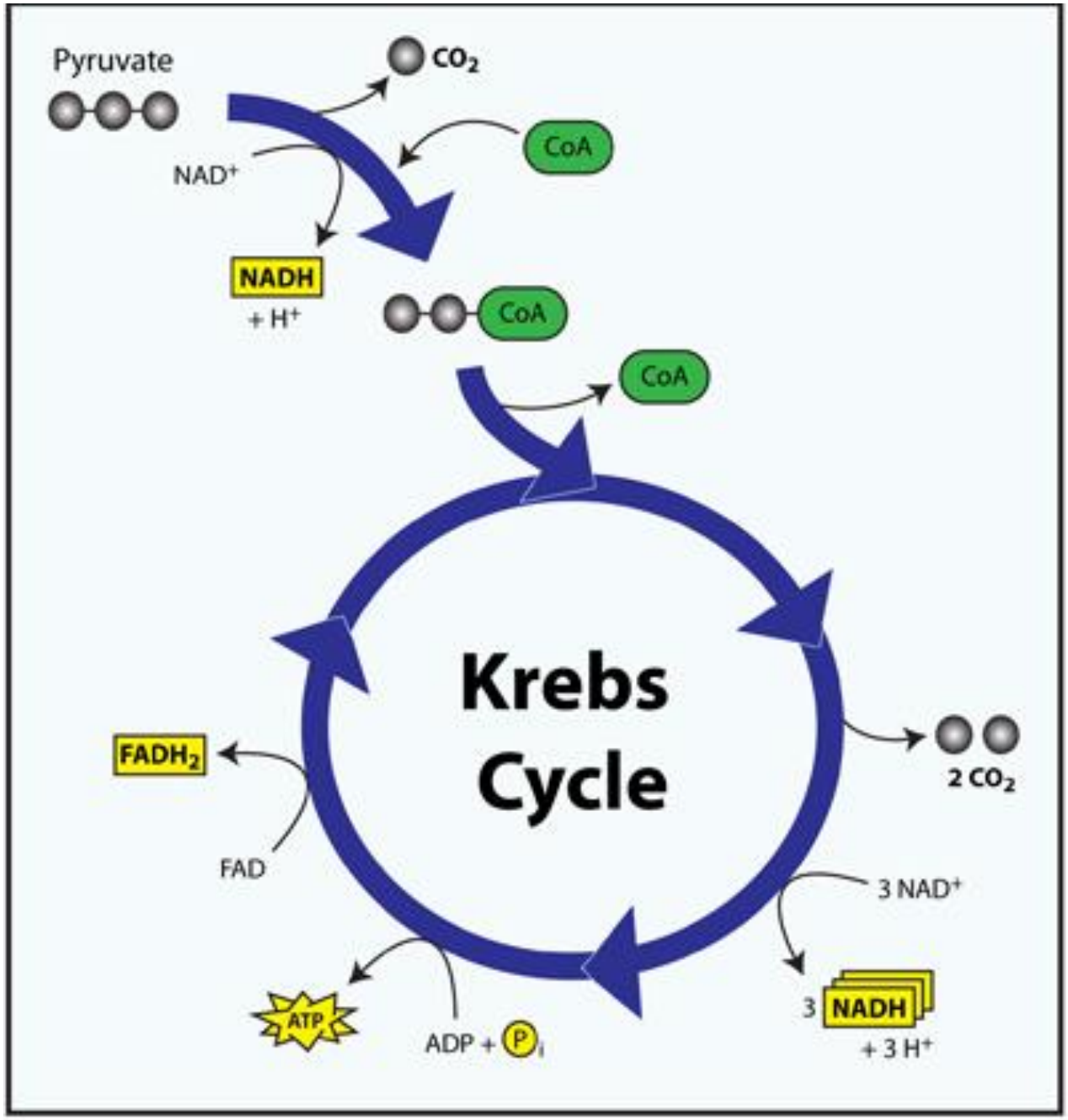

2 ADP
+ 2 P
2 ATP
Glucose
2 Pyruvic acid
2 NAD+
2 NADH
+ 2 H+

Step 2: Krebs Cycle

- Occurs in the mitochondria if enough O_2 is coming into the cell

- The pyruvic acid breaks off a CO_2 which leaves the cell and adds a coenzyme
  - This step creates acetyl CoA
  - Coenzymes bind to enzyme's active site to help the enzyme function

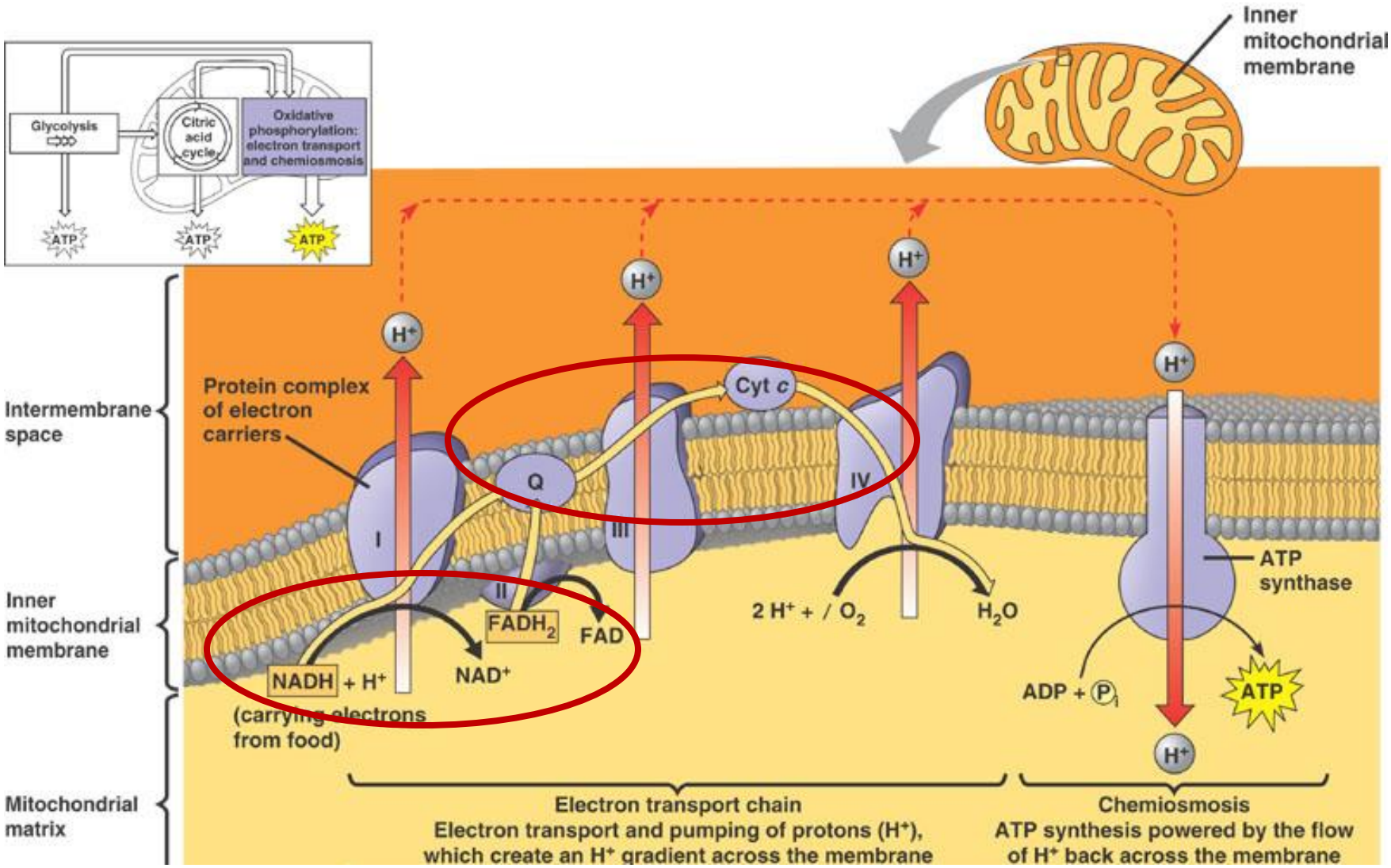
- Acetyl CoA binds to an enzyme and then to a 4-Carbon molecule (already present in the organelle) to start the Krebs cycle
  - This new molecule goes through a series of steps
- End results: **2 ATP**, NADH, and $FADH_2$ (another type of carrier molecule)
  - CO_2 leaves


Pyruvate
CO_2
CoA
NAD^+
NADH
$+ H^+$
CoA
CoA
Krebs Cycle
$FADH_2$
FAD
$2\ CO_2$
$3\ NAD^+$
3 NADH
$+ 3\ H^+$
ATP
ADP + P_i

Step 3: Electron Transport Chain

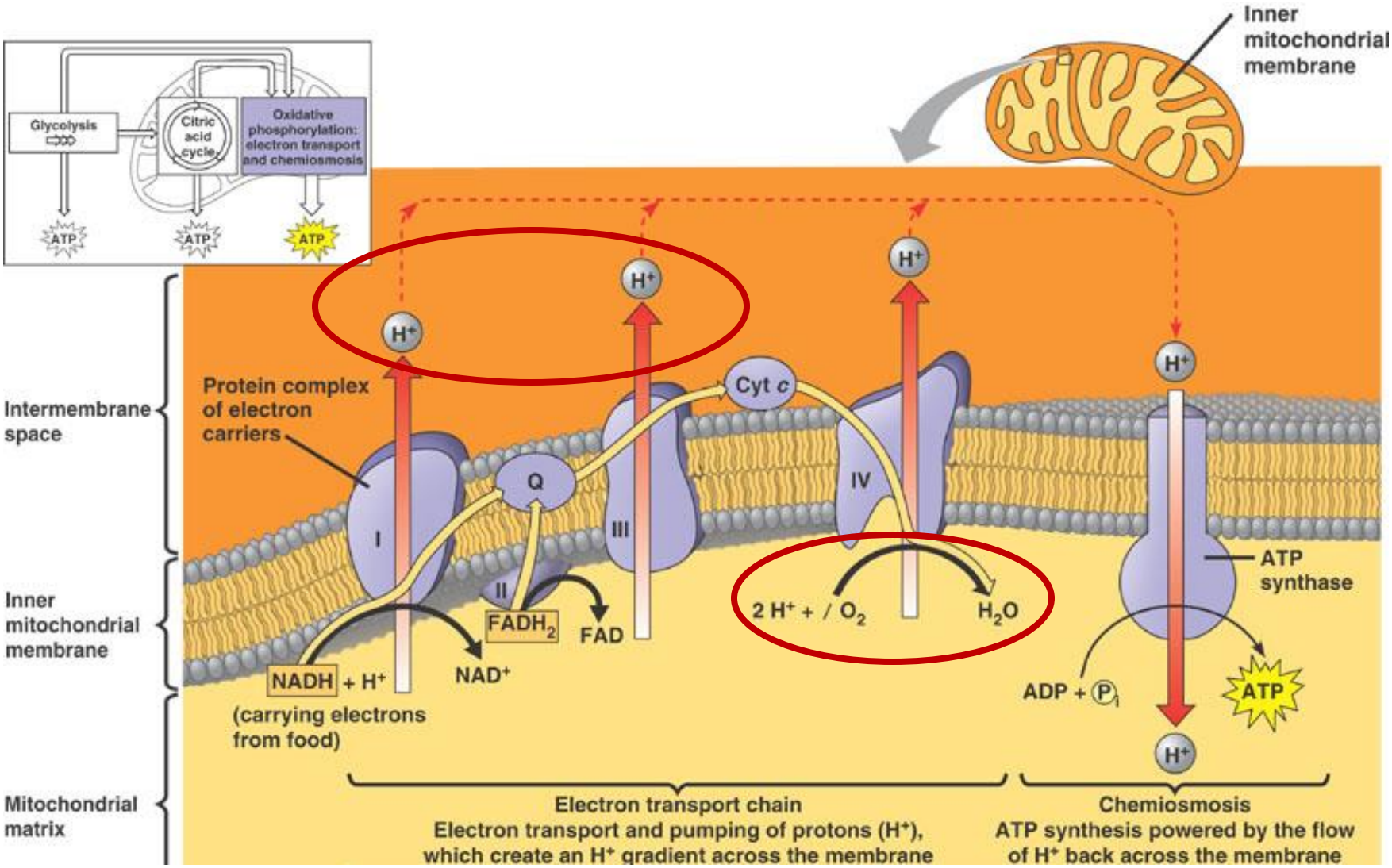
- All the NADH and $FADH_2$ made in the other steps move to the cristae (inner membrane)

- These molecules break off their H, release the electrons which will move through the series of proteins in the membrane of the mitochondria


Glycolysis
Citric acid cycle
Oxidative phosphorylation: electron transport and chemiosmosis
ATP
ATP
ATP
Inner mitochondrial membrane
Intermembrane space
Inner mitochondrial membrane
Mitochondrial matrix
Protein complex of electron carriers
H+
H+
H+
H+
Cyt c
Q
I
II
III
IV
FADH2
FAD
NADH + H+
NAD+
(carrying electrons from food)
2 H+ + 1/2 O2
H2O
ATP synthase
ADP + Pi
ATP
H+
Electron transport chain
Electron transport and pumping of protons (H+), which create an H+ gradient across the membrane
Chemiosmosis
ATP synthesis powered by the flow of H+ back across the membrane

- H+ move across the inner membrane through a protein powered by the flow of electrons

- At the end of the chain, electrons are given to O_2 and a left over H+ to make H_2O
  - Without O_2 present this step and the Krebs cycle cannot occur


Glycolysis
Citric acid cycle
Oxidative phosphorylation: electron transport and chemiosmosis
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Inner mitochondrial membrane
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Protein complex of electron carriers
H+
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NADH + H+
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(carrying electrons from food)
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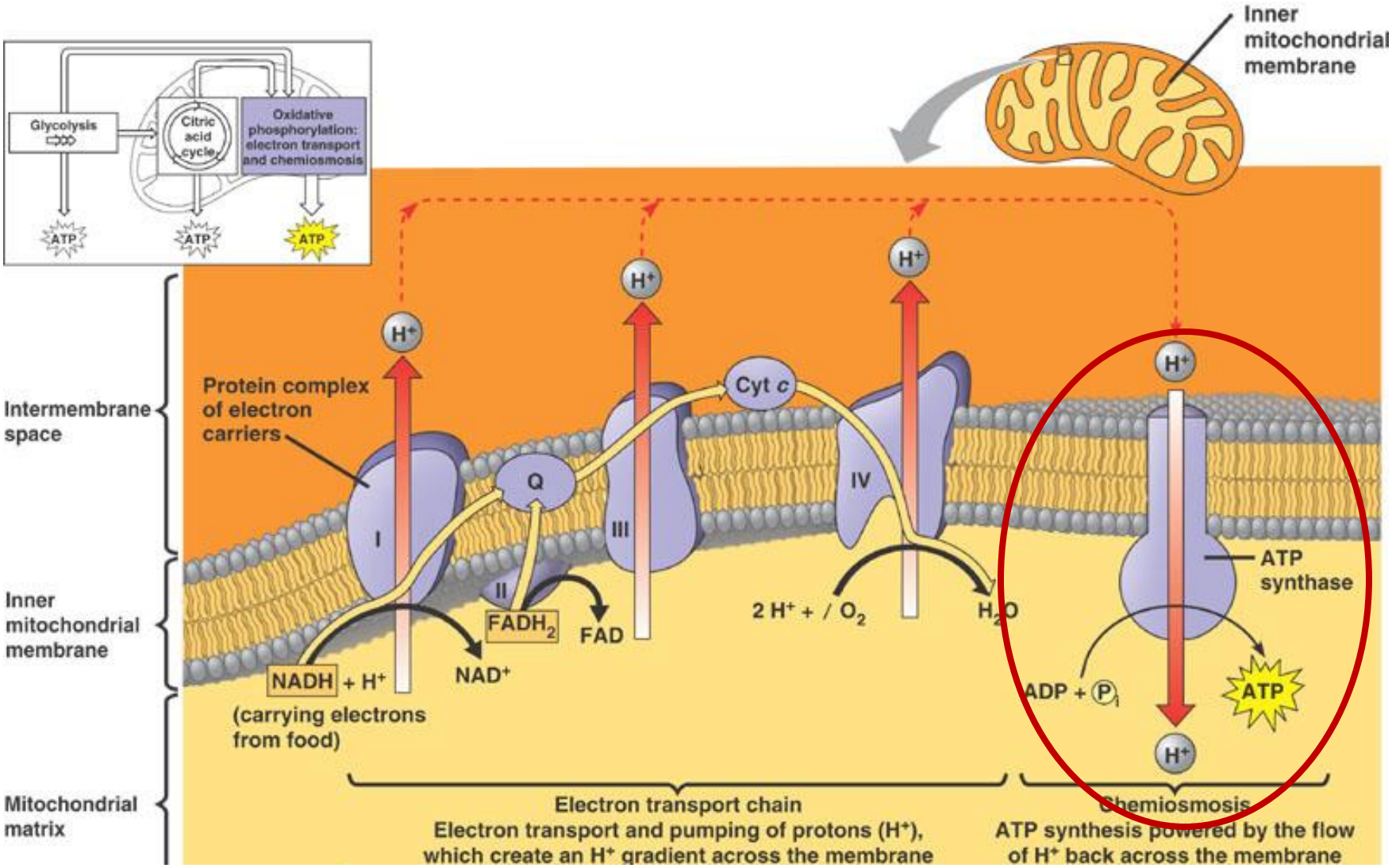
ATP synthase
ADP + P
ATP
H+
Electron transport chain
Electron transport and pumping of protons (H+), which create an H+ gradient across the membrane
Chemiosmosis
ATP synthesis powered by the flow of H+ back across the membrane

Electron Transport Chain

- Meanwhile, H+ builds up between the outer and inner membranes of the mitochondria and then diffuse back in through a special protein – ATP synthase (enzyme)
  - This allows a P to add to ADP to make ATP

- End Results: ~**34 ATP**
- Total ATP count for cell respiration from one glucose = ~38 ATP


Glycolysis
Citric acid cycle
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ATP
ATP
ATP
Inner mitochondrial membrane
Intermembrane space
Inner mitochondrial membrane
Mitochondrial matrix
Protein complex of electron carriers
H+
H+
H+
H+
Cyt c
Q
I
II
III
IV
FADH2
FAD
NADH + H+
NAD+
(carrying electrons from food)
2 H+ + 1/2 O2
H2O
ATP synthase
ADP + P i
ATP
Electron transport chain
Electron transport and pumping of protons (H+), which create an H+ gradient across the membrane
Chemiosmosis
ATP synthesis powered by the flow of H+ back across the membrane

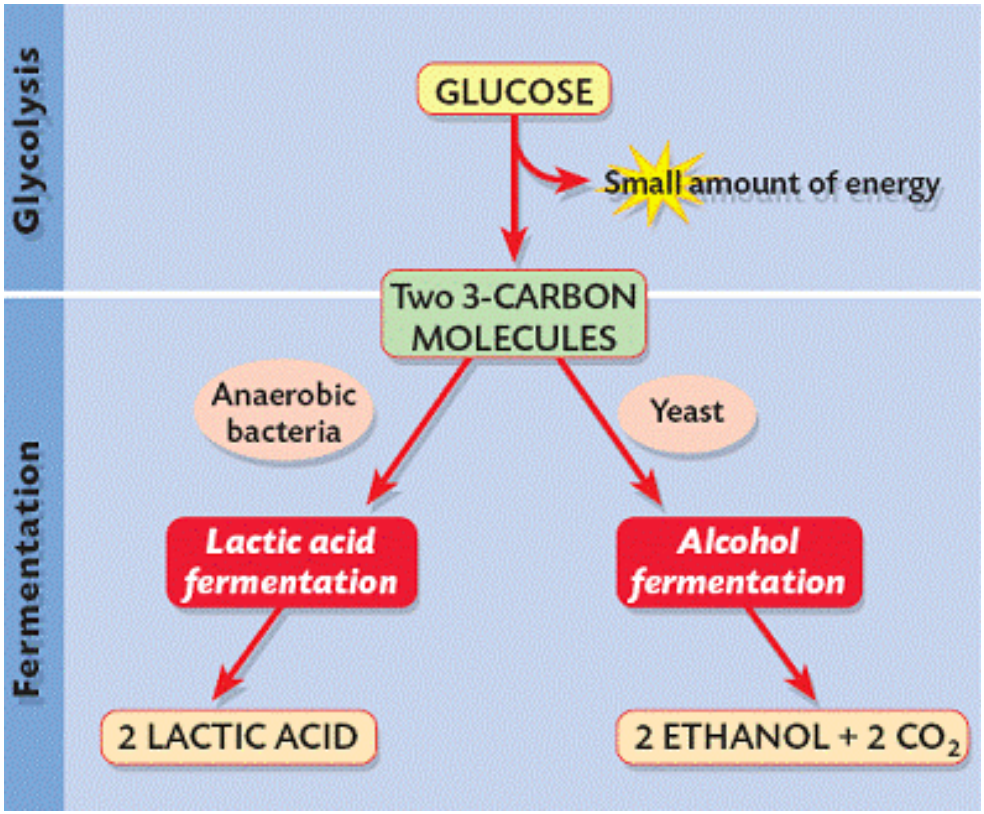
Fermentation (Anaerobic Respiration)

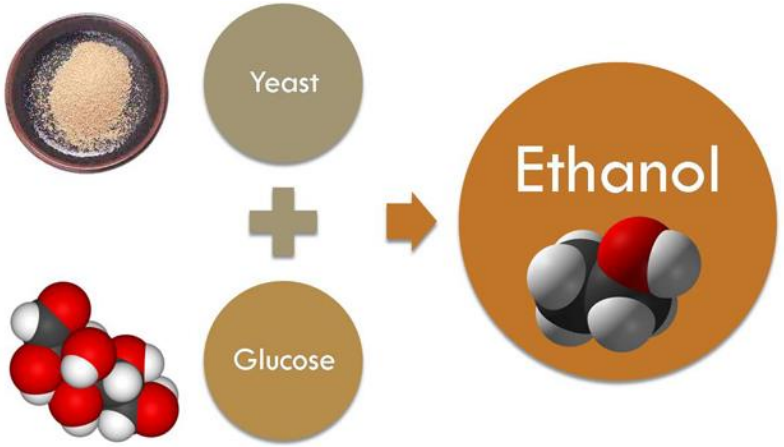
- Fermentation is a type of respiration that makes ATP when O_2 is NOT present

- 2 Types:
  - Alcoholic fermentation in fungus and bacteria
  - Lactic acid fermentation in animals and bacteria

- After glycolysis occurs, pyruvic acid is converted into lactic acid or ethyl alcohol instead of moving into the mitochondria and completing the next 2 steps of aerobic respiration

- End Result: **only 2 ATP**
  - This is much less than cellular respiration





$$C_6H_{12}O_6 \rightarrow 2\ C_2H_5OH + 2\ CO_2$$

- Cell Respiration