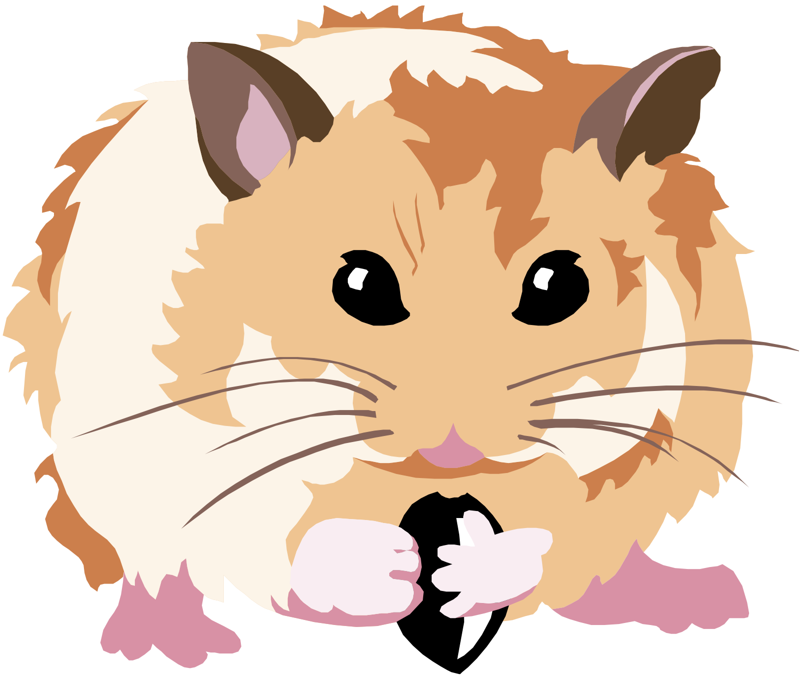
Respiration and Photosynthesis

The Ying and Yang of Life.

Why?

- You've always been told that you must eat and breathe.
- Why?
- In this unit we will attempt to answer those questions.



1st Law of Thermodynamics

- This unit discusses energy
  - During photosynthesis and respiration, we are NOT creating energy (or destroying)
  - We are only changing the form it takes
    - Light energy
    - Chemical energy

2^{nd} Law of Thermodynamics

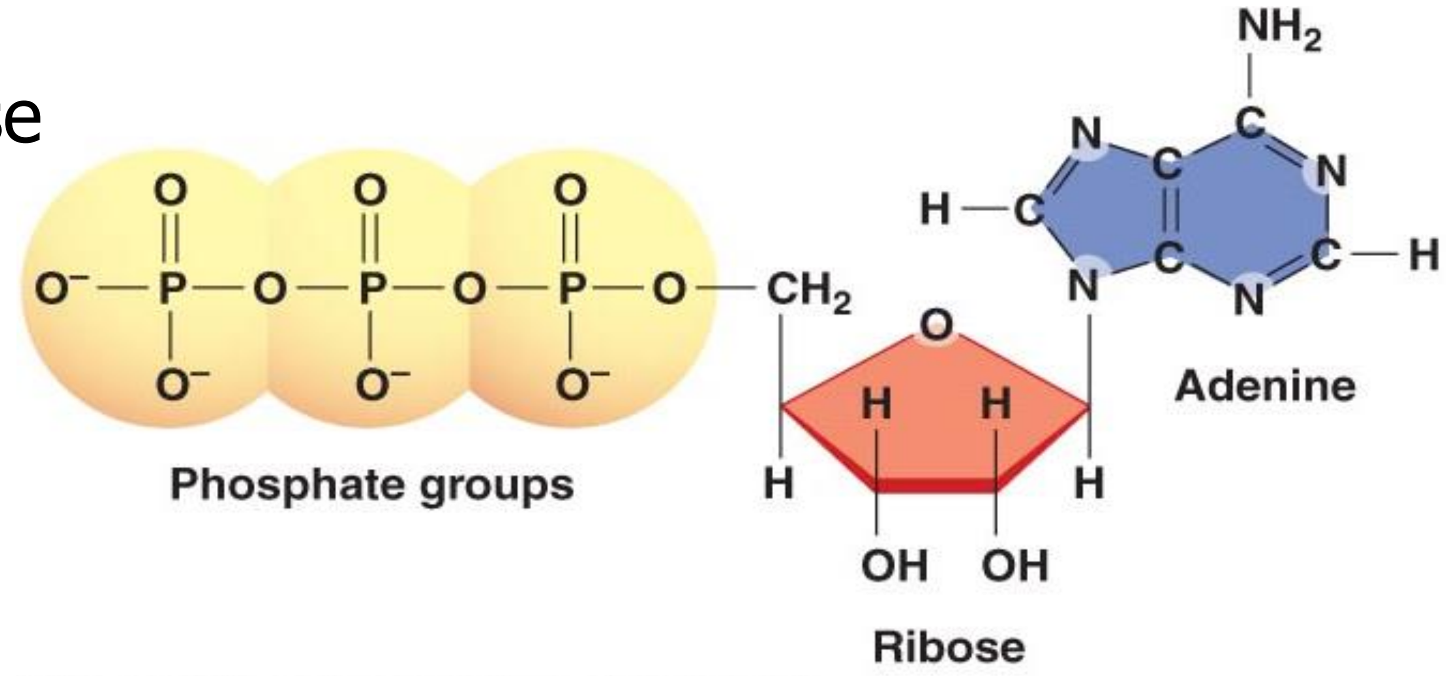
- Entropy always decreases with time
  - Which is another way of saying
    - Disorder always decreases with time
- This means that
  - It takes energy to maintain structure
    - You have to "spend" a bit to get something

Energy Storage In the Cell

- Remember, energy can not be created. So, how does a cell store energy?
  - Adenosine Triphosphate
    - ATP
- ATP is the "chemical" or "useable" energy that we have talked about before

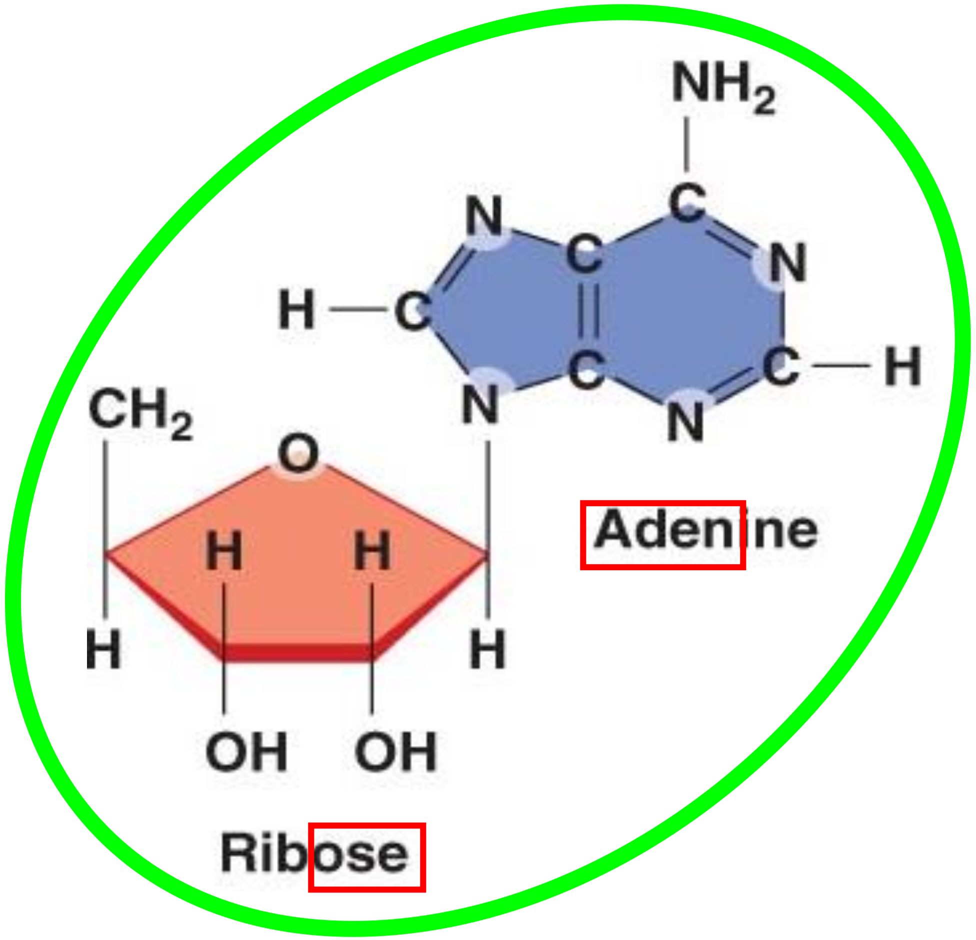
ATP

- ATP is a high energy **storing** molecule composed of three parts:
  - An adenine
  - A five carbon sugar, ribose
  - Three phosphate groups

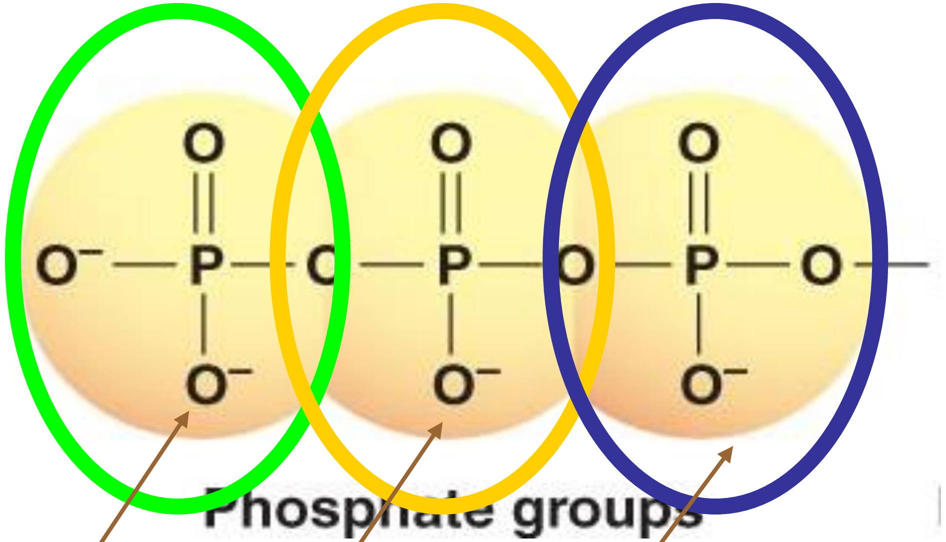


ATP

Adenosine



ATP



Triphosphate

1, one phosphate

2, two phosphates

3, three phosphates

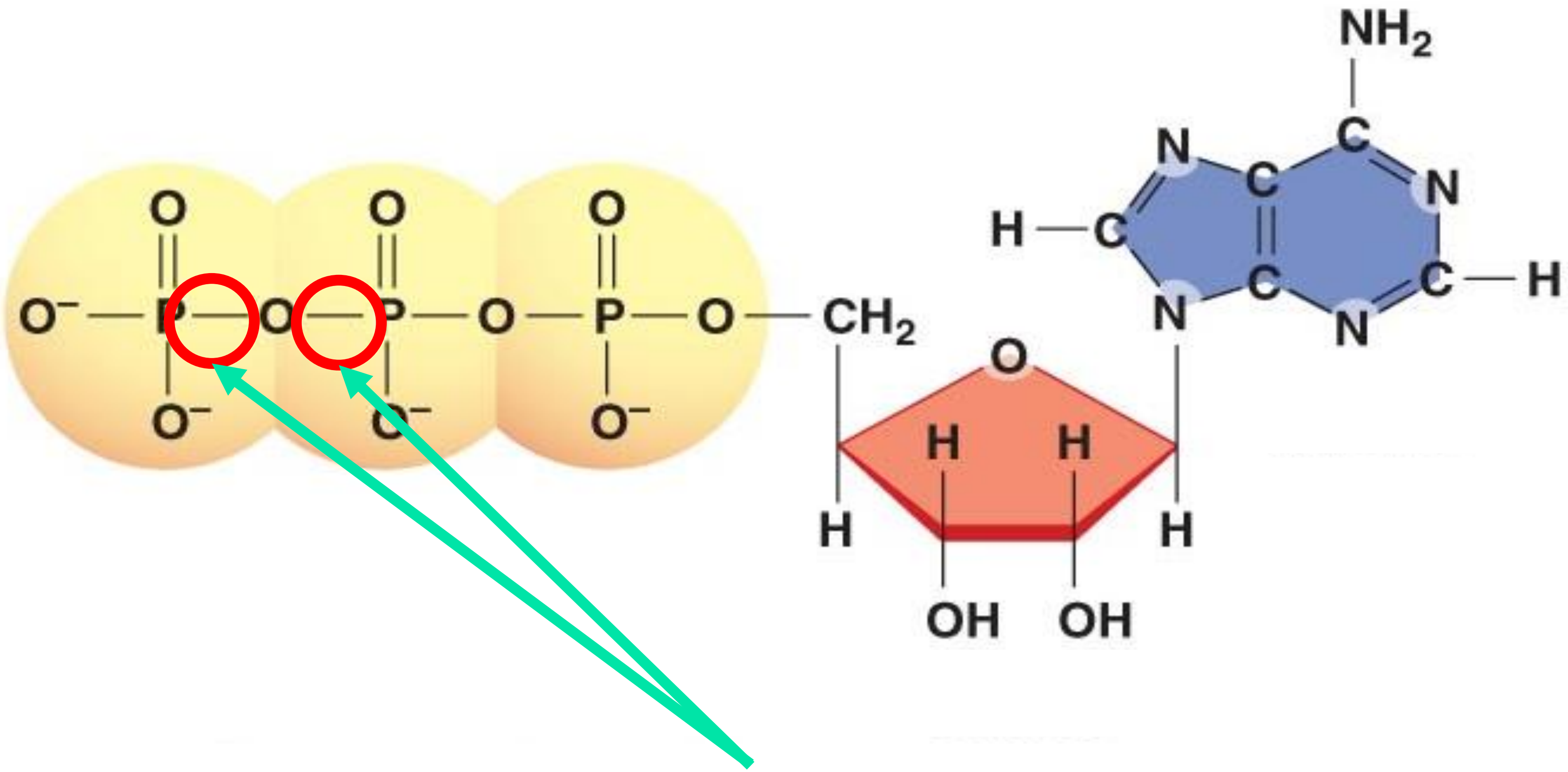
Ah-ah-ah

ATP

- There is a great deal of energy stored between the phosphates bonds of ATP
  - It is like a battery – it merely holds energy until you want to use it

* ATP IS NOT ENERGY *

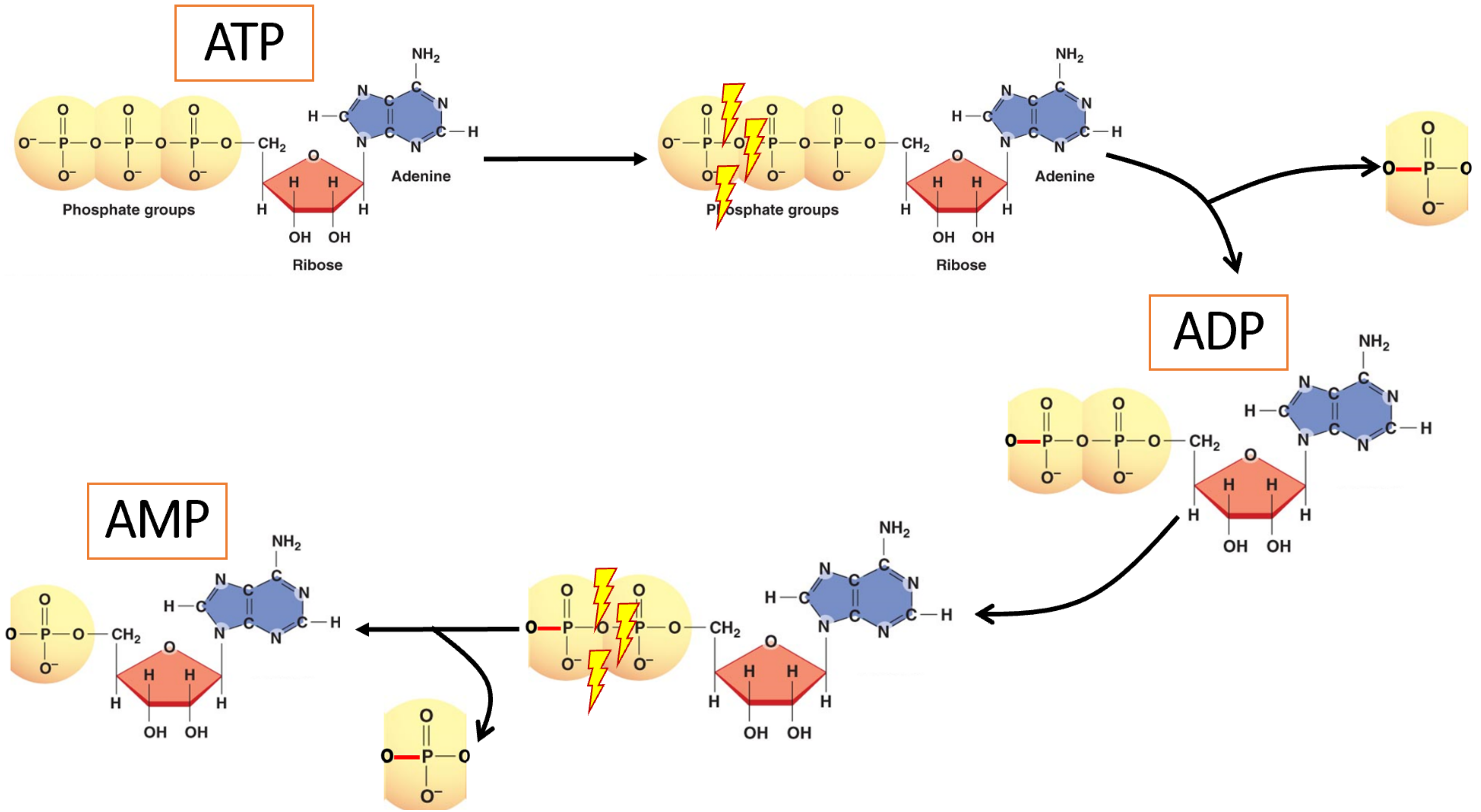
ATP



There are two very high energy bonds in ATP

ATP

- When the bonds are broken, energy is released and the ATP molecule becomes an adenosine diphosphate molecule
  - ADP
- The bonds can be further broken, more energy can be released, and the ADP molecule becomes an adenosine monophosphate molecule
  - AMP



ATP
Phosphate groups
Ribose
Adenine
ADP
AMP

ATP

- When the high energy bond between the phosphates is broken
  - The energy stored in the bond is changed into a type of energy that can be used by the cell
    - But it is not created (1^{st} Law of Thermodynamics)

Why Eat Food?

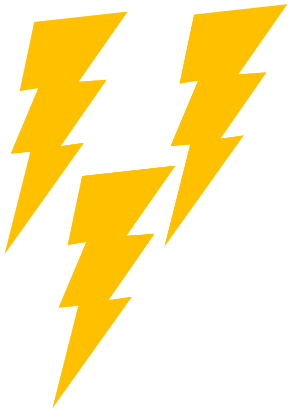
- Food contains carbohydrates, like glucose, that can be broken down by the body




CELLULAR RESPIRATION

- Glucose is the molecule that the cells break down and use the energy released to create ATP molecules

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



Cellular Respiration

- Cellular Respiration has 3 stages
  - Glycolysis → cytoplasm
  - The Krebs Cycle
  - Electron Transport Chain
- In each of these stages, ATP is produced

Step 1: Glycolysis

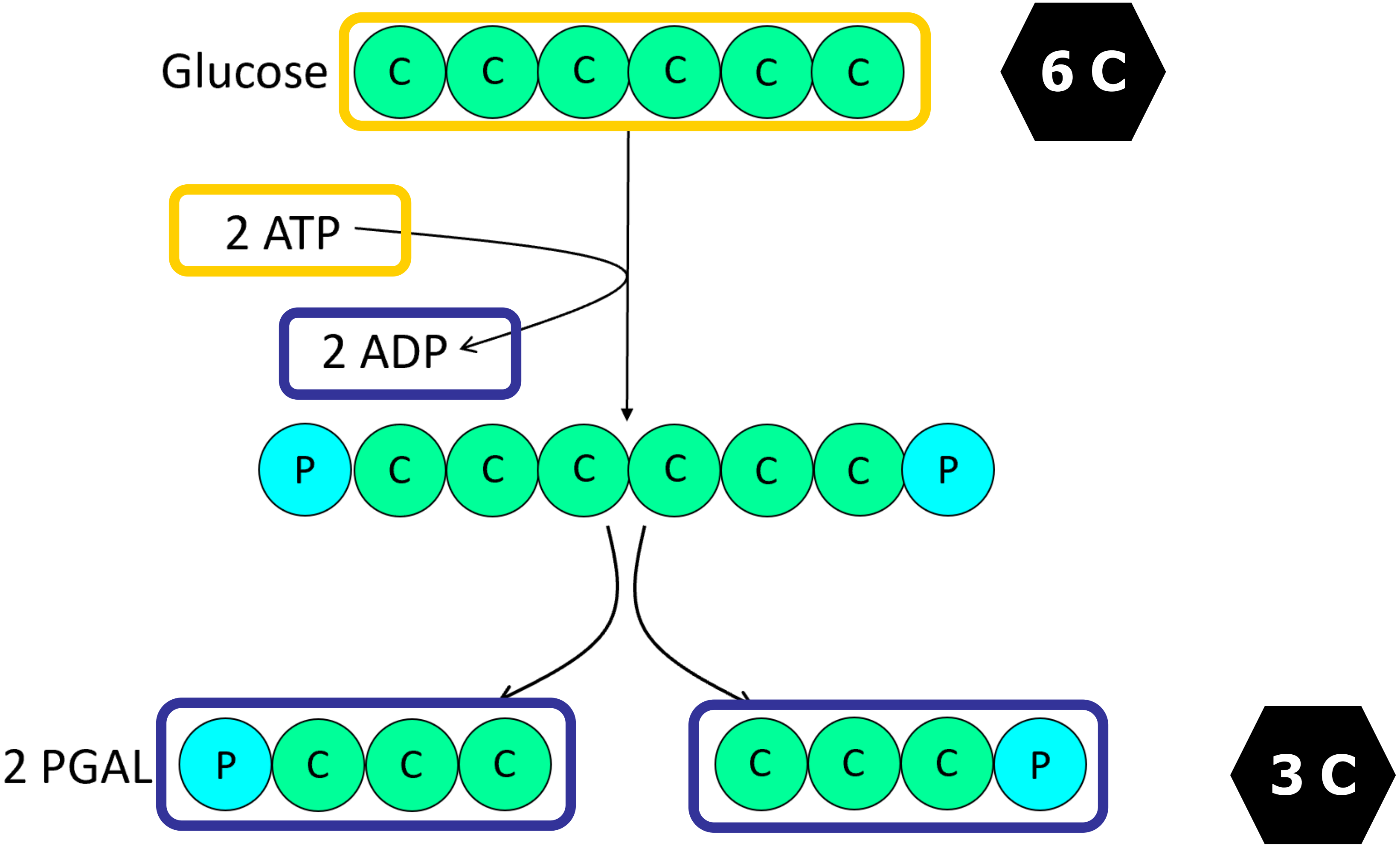
- glyco- : glucose
- -lysis : to break down

- Glycolysis : to break down glucose

- Occurs in the cytoplasm

Glycolysis

- 2 ATP molecules are used to add two phosphate groups to glucose
- That molecule is then broken down into 2 molecules of PGAL
  - A 3-carbon molecule with a phosphate



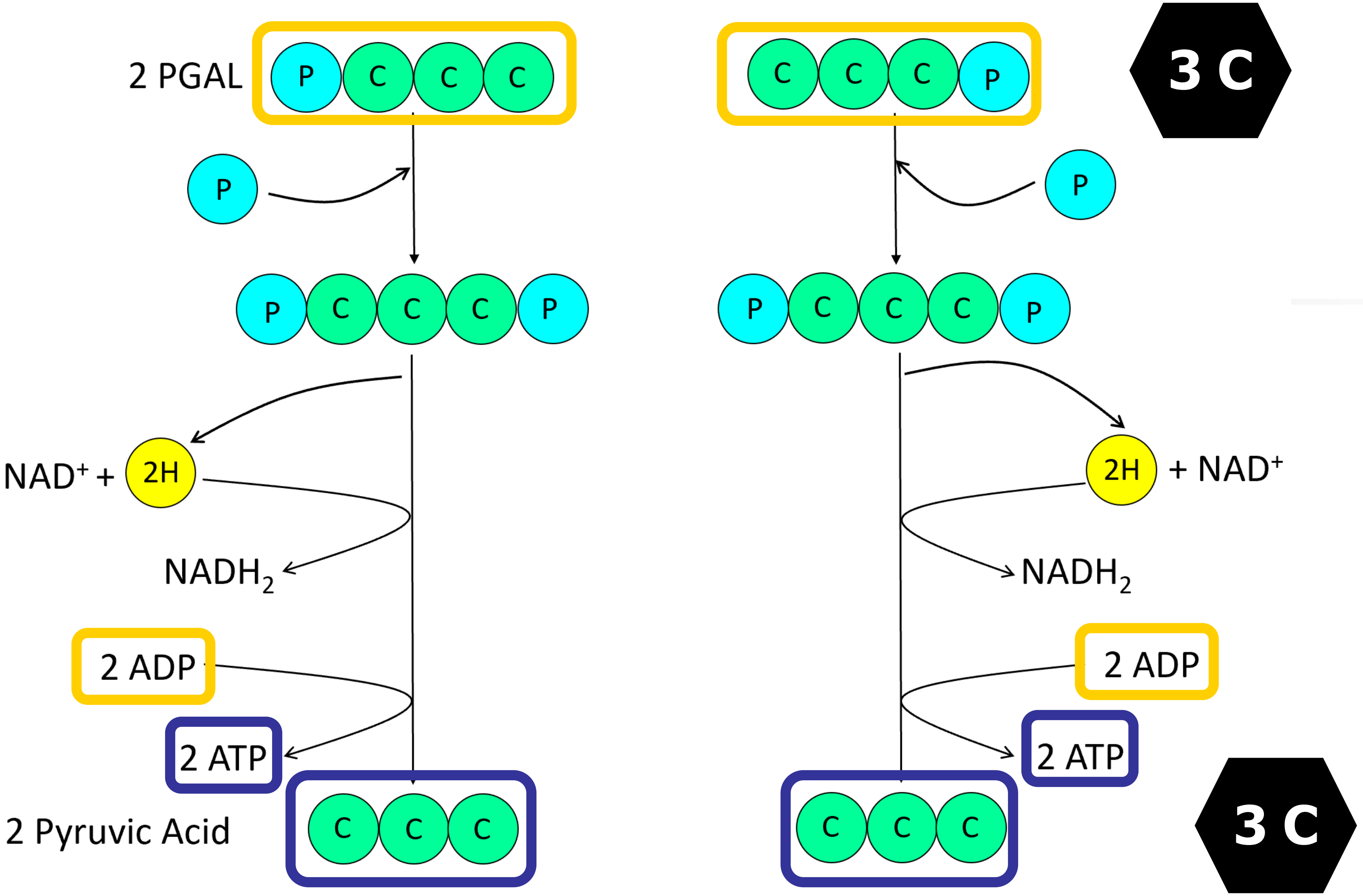
Spent	Produced
1 Glucose 2 ATP	2 ADP 2 PGAL

Glycolysis

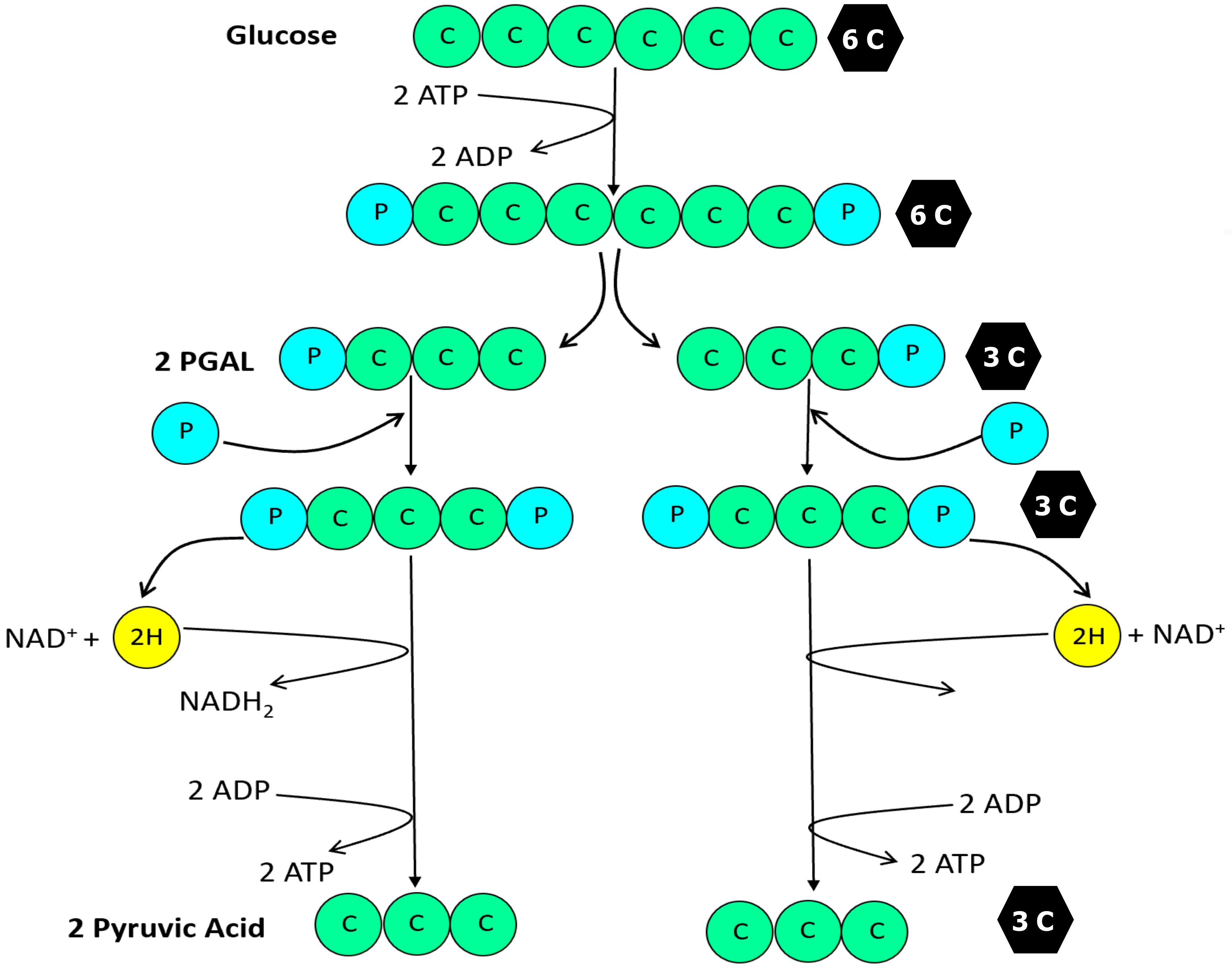
- Then, a phosphate group is added to each PGAL
- Two hydrogen atoms are removed
  - Picked up by a molecule called NAD+ to form $NADH_2$

Glycolysis

- When each PGAL gets a phosphate
  - 2 ATP molecules are produced
  - The PGAL with a phosphate is called pyruvic acid (3-carbon molecule)



Spent	Produced
2 PGAL 4 ADP 2 NAD^+	2$NADH_2$ 4 ATP 2 Pyruvic Acid


Glucose
6 C
2 ATP
2 ADP
6 C
2 PGAL
3 C
3 C
NAD+ +
2H
NADH2
2H
+ NAD+
2 ADP
2 ATP
2 ADP
2 ATP
2 Pyruvic Acid
3 C

Glycolysis

- We "spent" 2 ATP
- But produced 4 ATP

- Net: 2 ATP

- **Total (so far): 2 ATP**

2 Paths for Pyruvate after glycolysis

Aerobic Respiration

- If oxygen levels are high

aerobic

"with oxygen"

Anaerobic Respiration

- If oxygen levels are low

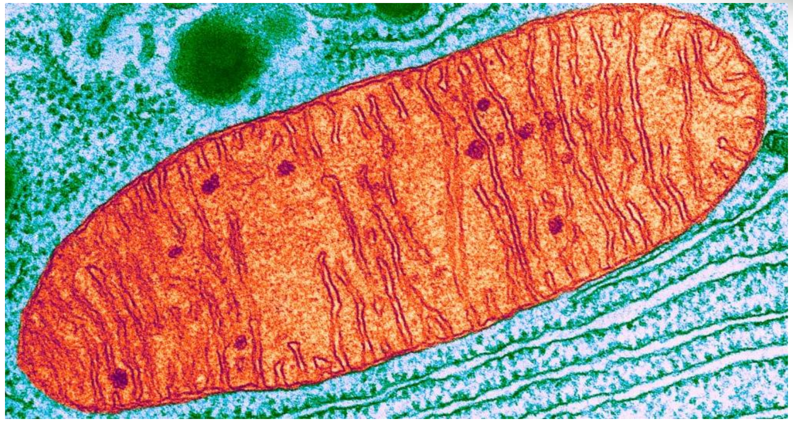
anaerobic

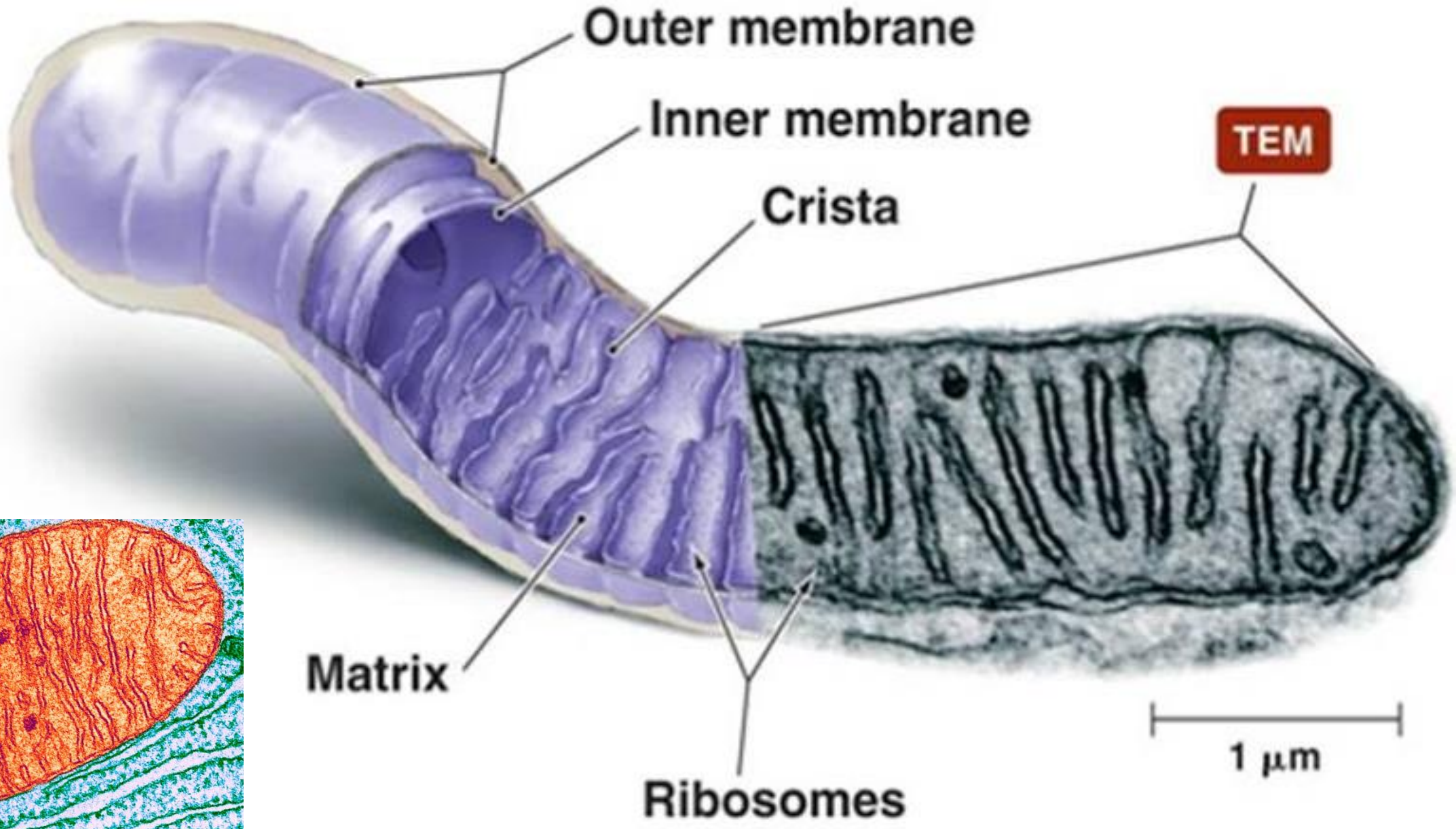
"without oxygen"

- -aero- : air
- an- : without
- -obic : relating to life

Aerobic Respiration

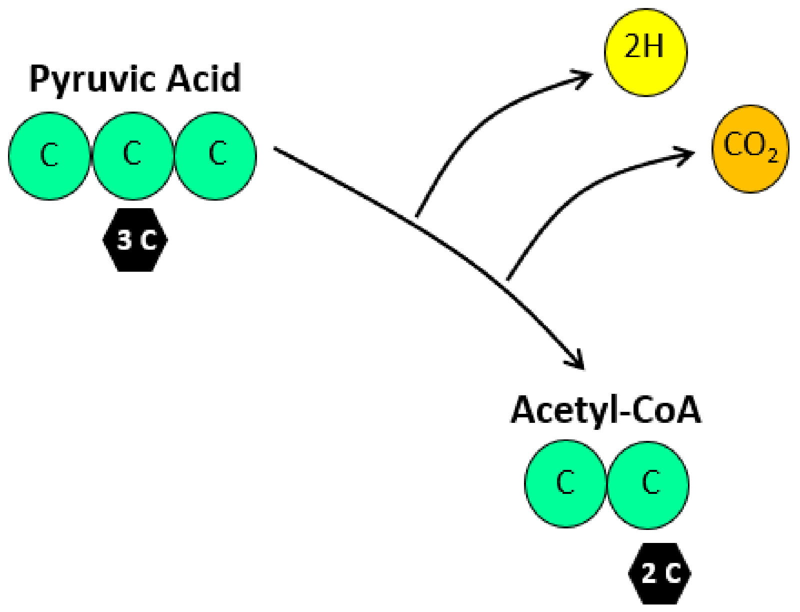
- Pyruvic acid molecules moves to the inner membrane of the mitochondria





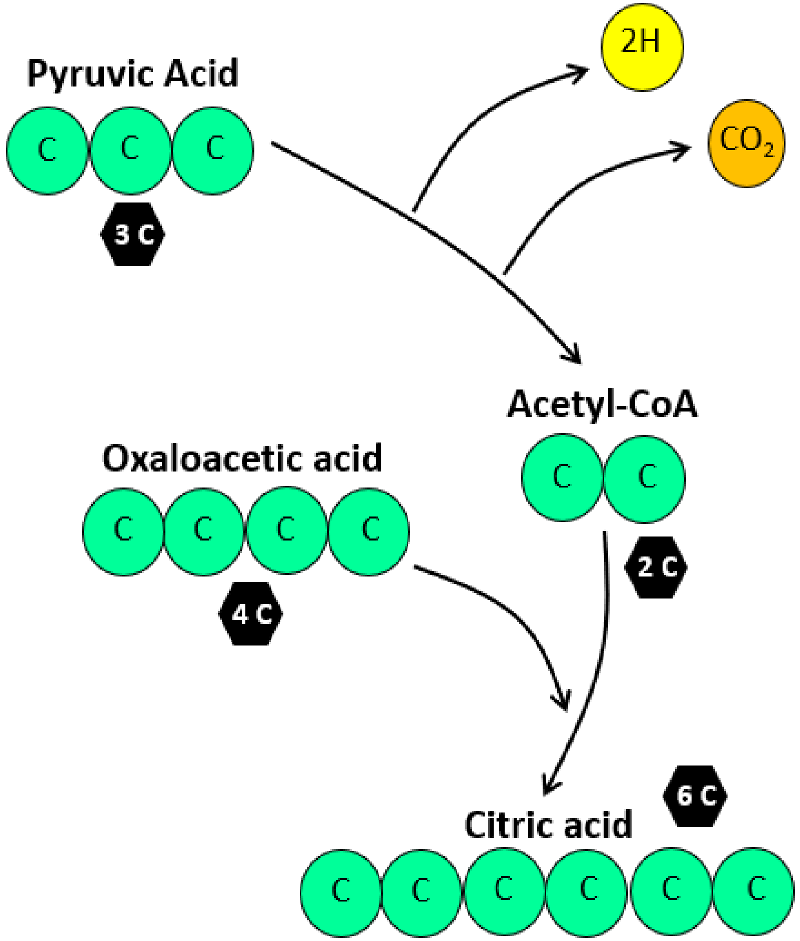
The Krebs Cycle

- A molecule of CO_2 and two hydrogen ions are removed from pyruvic acid
  - This forms a 2-carbon Acetyl-CoA molecule.
  - The hydrogens received by an NAD^+ molecule


Pyruvic Acid
C
C
C
3 C
2H
CO_2
Acetyl-CoA
C
C
2 C

The Krebs Cycle

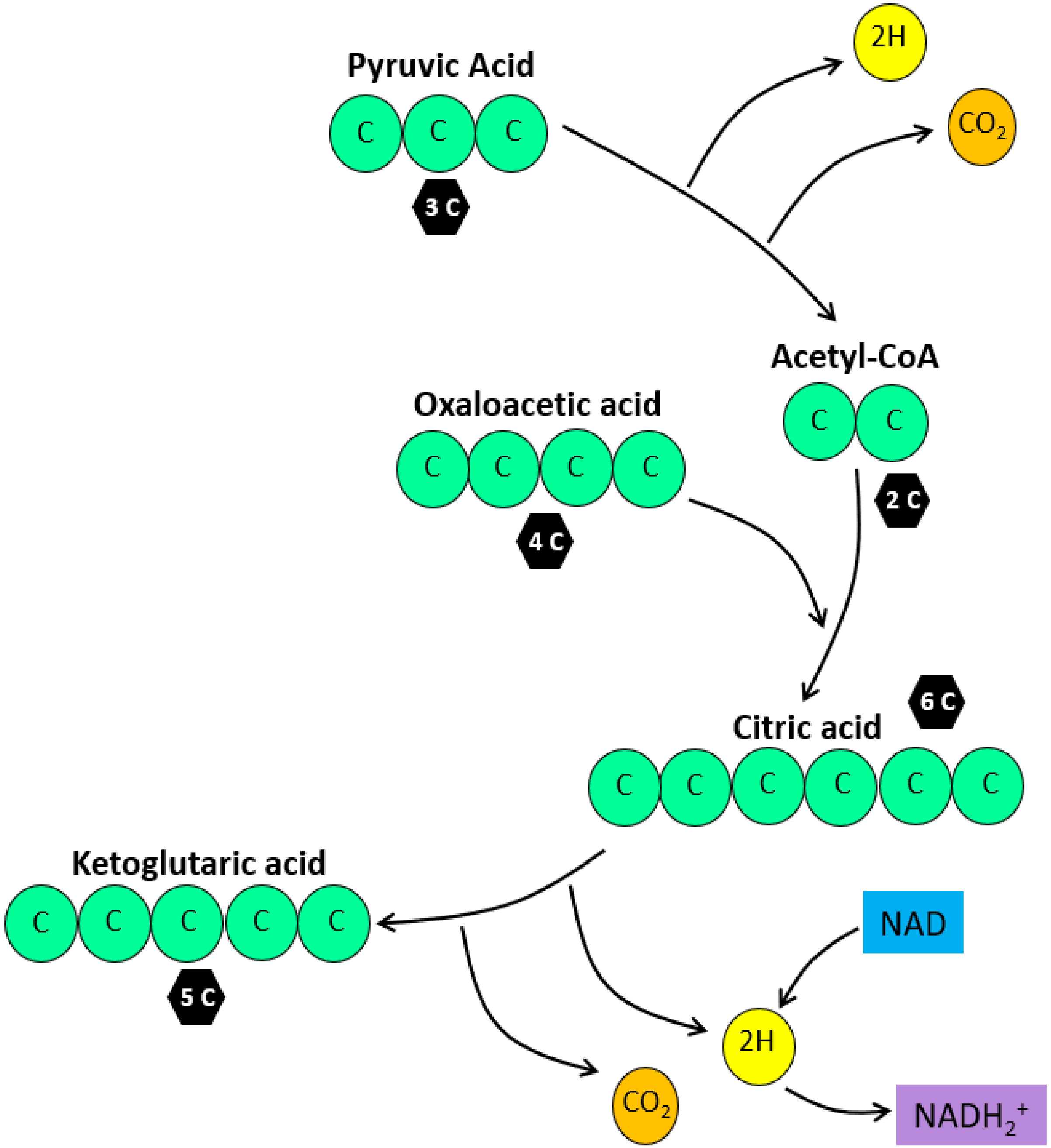
- When acetyl-CoA enters the cycle, a 4-carbon molecule called oxaoacetic bonds to it
  - This forms a 6-carbon molecule called citric acid.



Pyruvic Acid
C
C
C
3 C
2H
CO2
Acetyl-CoA
C
C
2 C
Oxaloacetic acid
C
C
C
C
4 C
6 C
Citric acid
C
C
C
C
C
C

The Krebs Cycle

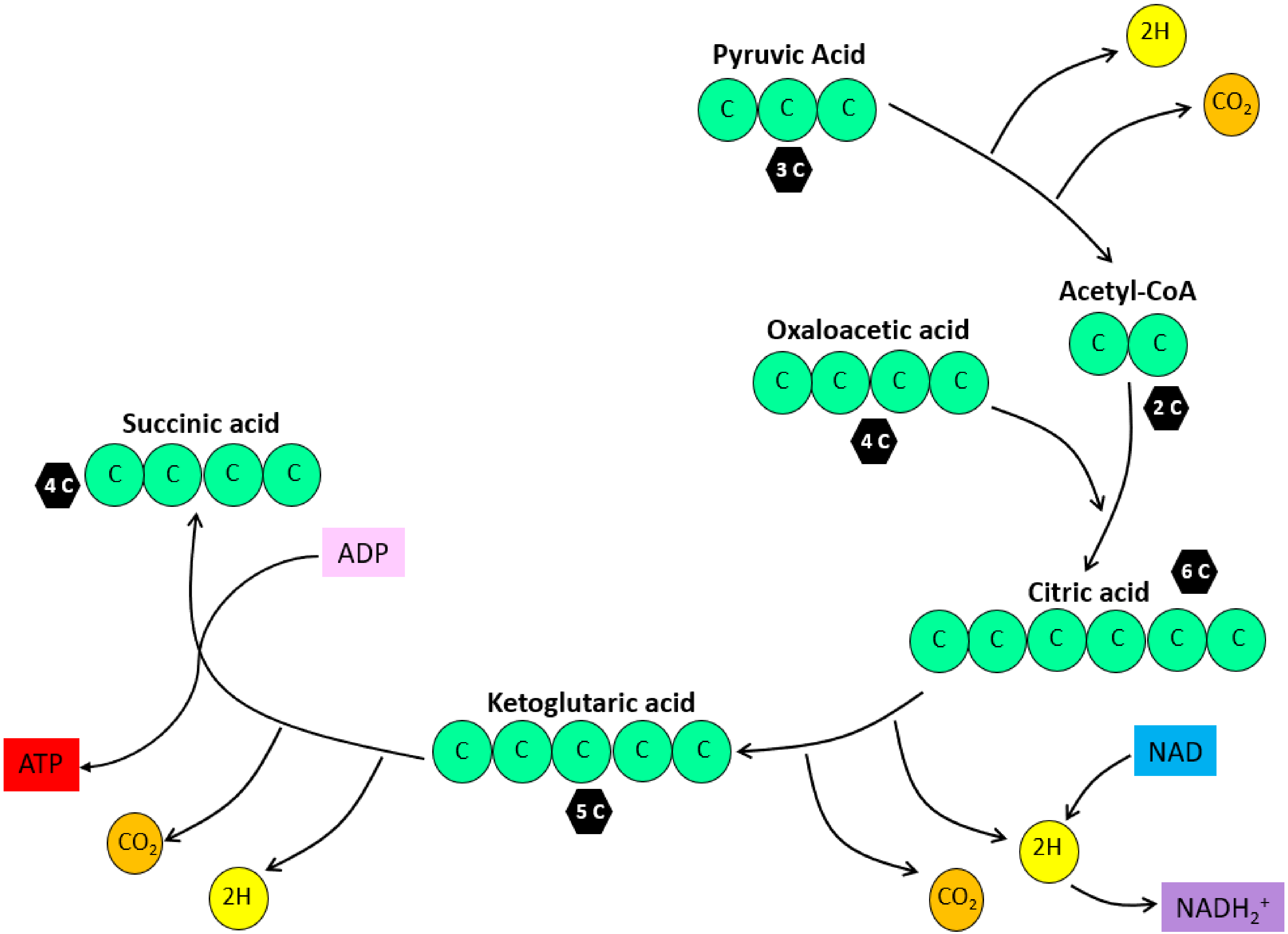
- CO_2 is removed from the citric acid molecule
  - This produces a 5-carbon molecule called ketoglutaric acid.
- Two hydrogen ions are also removed.
  - The hydrogen ions are picked up by an ion receptor molecule called NAD, which becomes $NADH_2$



Pyruvic Acid
C C C
3 C
2H
CO2
Acetyl-CoA
C C
2 C
Oxaloacetic acid
C C C C
4 C
6 C
Citric acid
C C C C C C
Ketoglutaric acid
C C C C C
5 C
NAD
2H
CO2
NADH2+

The Krebs Cycle

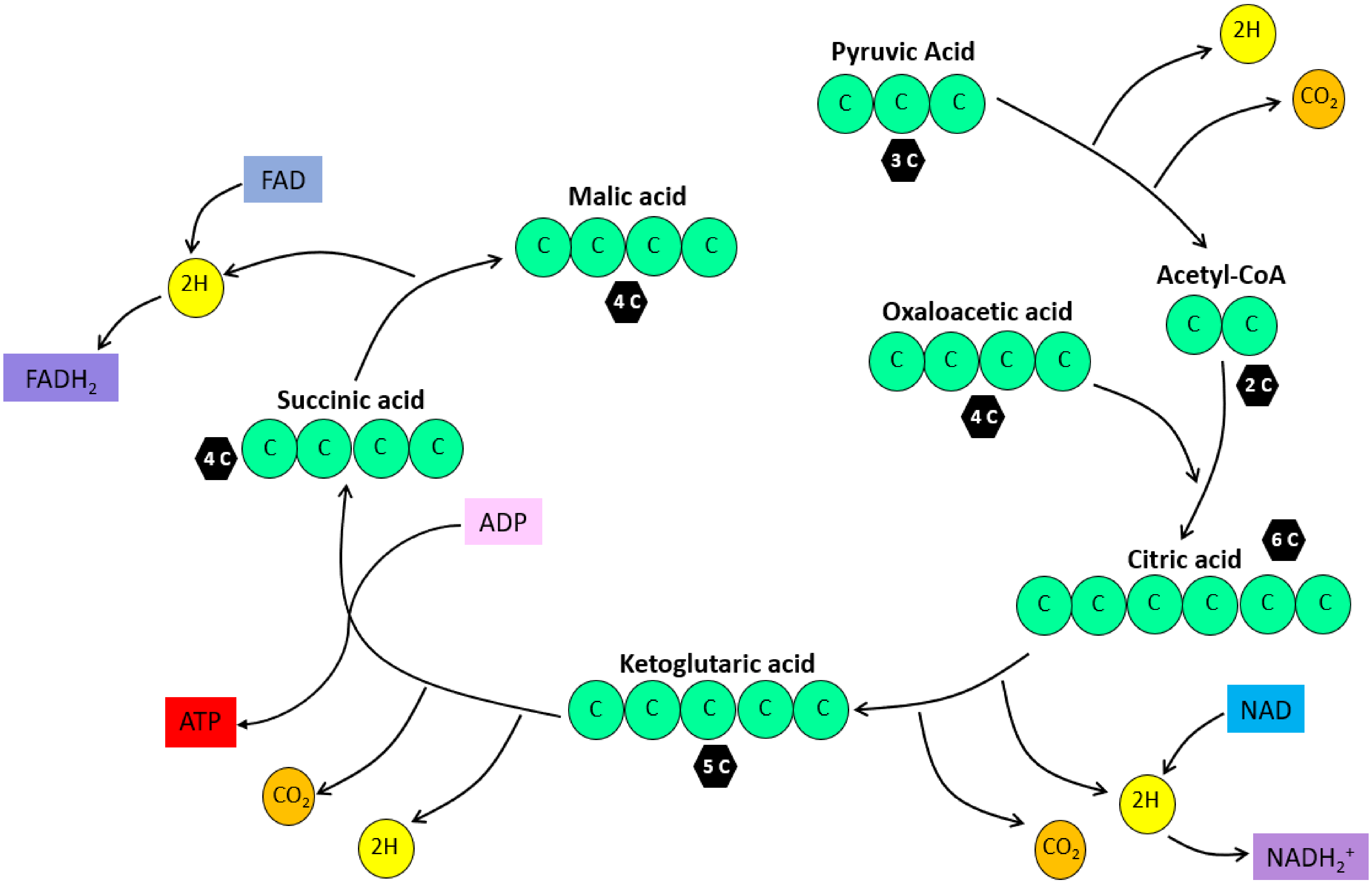
- Another CO_2 molecule and two more hydrogen ions are removed
  - This forms succinic acid, a 4-carbon molecule.
- At this point, there has been enough energy released to form one more ATP molecule.



Pyruvic Acid
C C C
3 C
2H
CO_2
Acetyl-CoA
C C
2 C
Oxaloacetic acid
C C C C
4 C
Citric acid
6 C
C C C C C C
NAD
2H
$NADH_2^+$
CO_2
Ketoglutaric acid
C C C C C
5 C
Succinic acid
4 C
C C C C
ADP
ATP
CO_2
2H

The Krebs Cycle

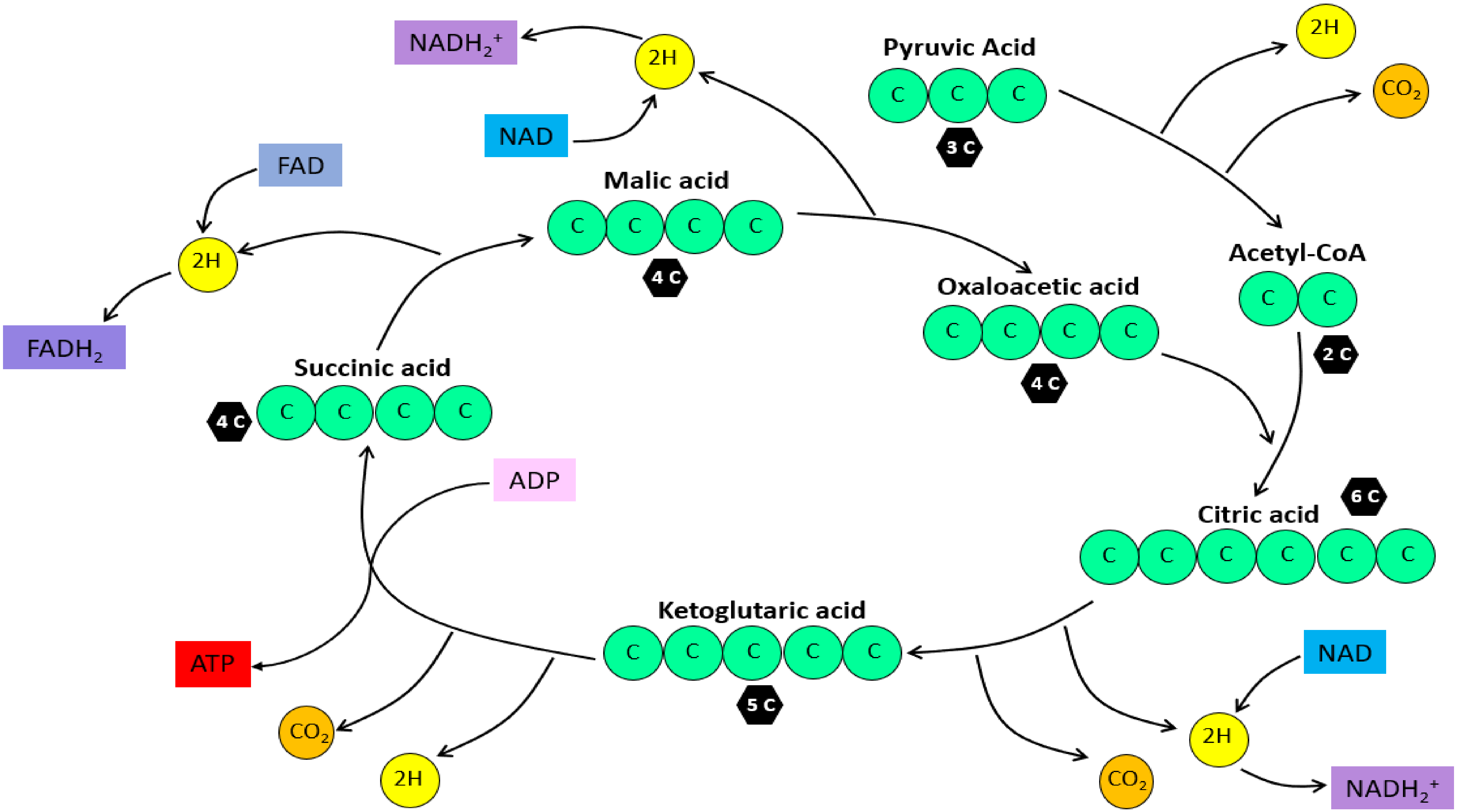
- Two more hydrogen ions are removed, but this time they are stored on a molecule called FAD.
  - FAD becomes $FADH_2$
- The new 4-carbon molecule is called malic acid



Pyruvic Acid
C C C
3 C
2H
CO2
Acetyl-CoA
C C
2 C
Oxaloacetic acid
C C C C
4 C
Citric acid
6 C
C C C C C C
NAD
2H
NADH2+
CO2
Ketoglutaric acid
C C C C C
5 C
CO2
2H
ATP
ADP
Succinic acid
4 C
C C C C
Malic acid
C C C C
4 C
FAD
2H
FADH2

The Krebs Cycle

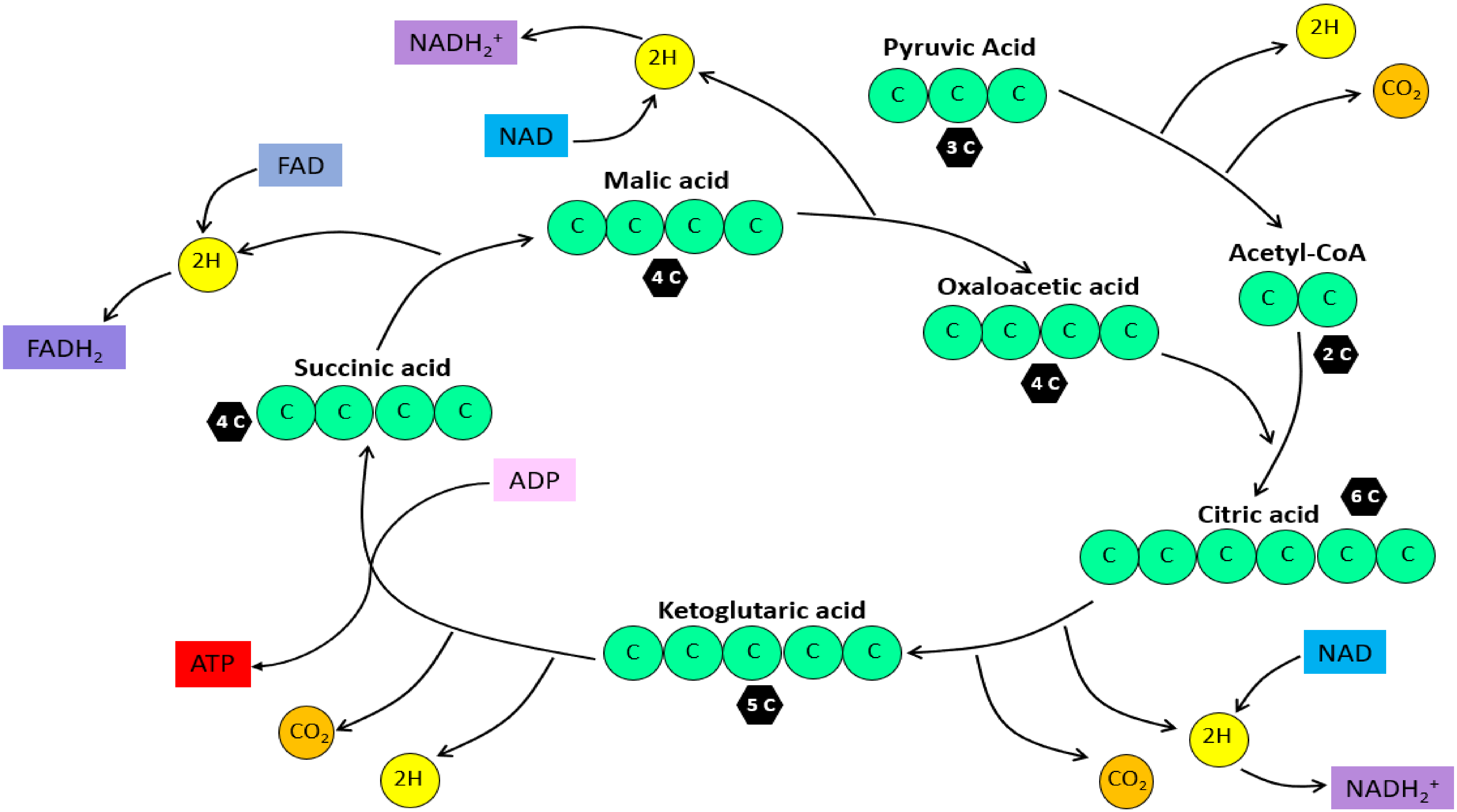
- Two more hydrogen ions are removed and stored on a NAD molecule
- This produces the 4-carbon molecule oxaloacetic acid.
  - Does that sound familiar?
  - It should!



Pyruvic Acid
C C C
3 C
2H
CO₂
Acetyl-CoA
C C
2 C
Oxaloacetic acid
C C C C
4 C
Citric acid
6 C
C C C C C C
NAD
2H
$NADH_2^+$
CO_2
Ketoglutaric acid
C C C C C
5 C
CO_2
2H
ADP
ATP
Succinic acid
4 C
C C C C
FAD
2H
$FADH_2$
Malic acid
C C C C
4 C
NAD
2H
$NADH_2^+$

The Krebs Cycle

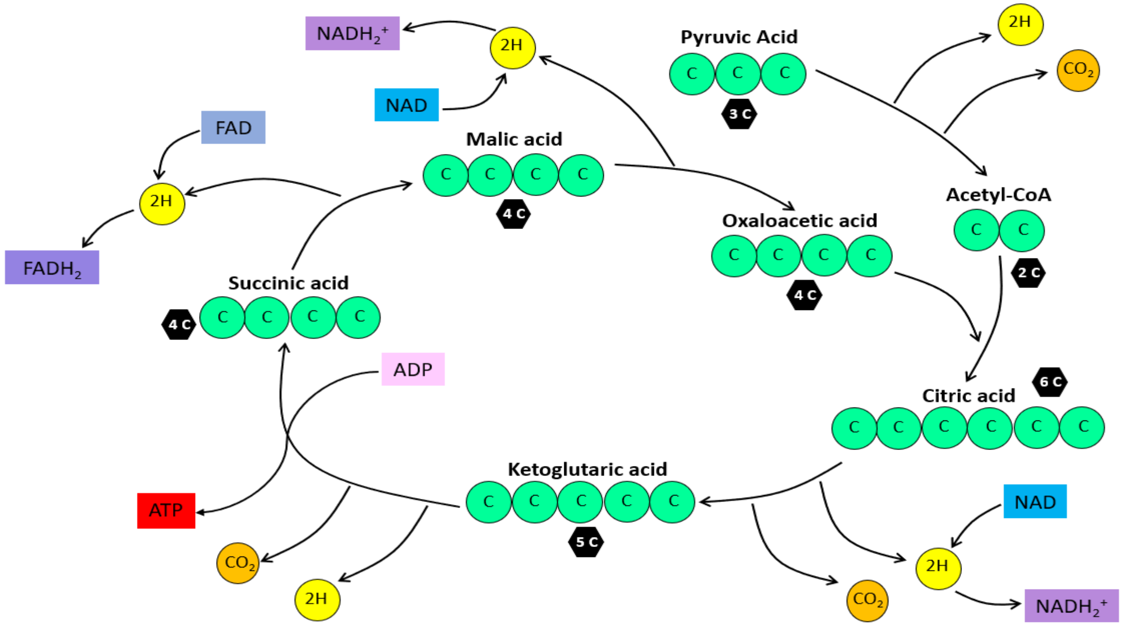
- Oxaloacetic acid is what we combined Acetyl-CoA with to make citric acid
  - This is why we call it a cycle!

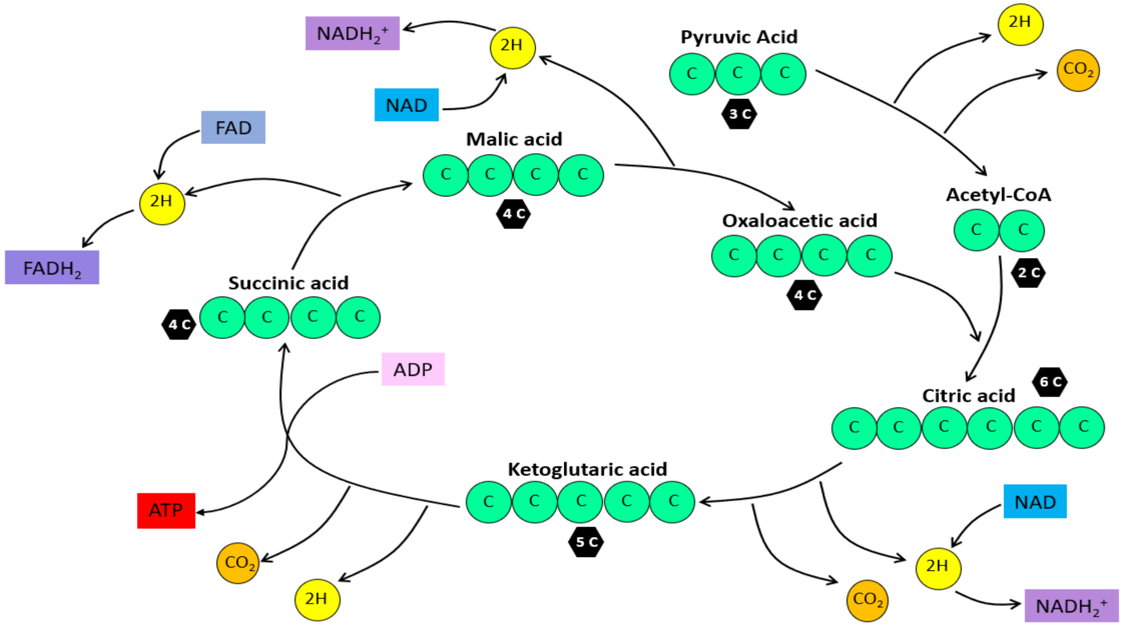


Pyruvic Acid
C C C
3 C
2H
CO₂
Acetyl-CoA
C C
2 C
Oxaloacetic acid
C C C C
4 C
Citric acid
6 C
C C C C C C
NAD
2H
NADH₂⁺
CO₂
Ketoglutaric acid
C C C C C
5 C
CO₂
2H
ATP
ADP
Succinic acid
4 C
C C C C
FAD
2H
FADH₂
Malic acid
C C C C
4 C
NAD
2H
NADH₂⁺

The Krebs Cycle

- We had 2 pyruvic acids, so this cycle happens 2 times for every glucose molecule





The Krebs Cycle

- We didn’t “spend” anymore ATP
- And we produced 2 ATP

- Net: 2 ATP

- **Total (so far): 4 ATP**

What Happens to the $NADH_2$ and the FADH?

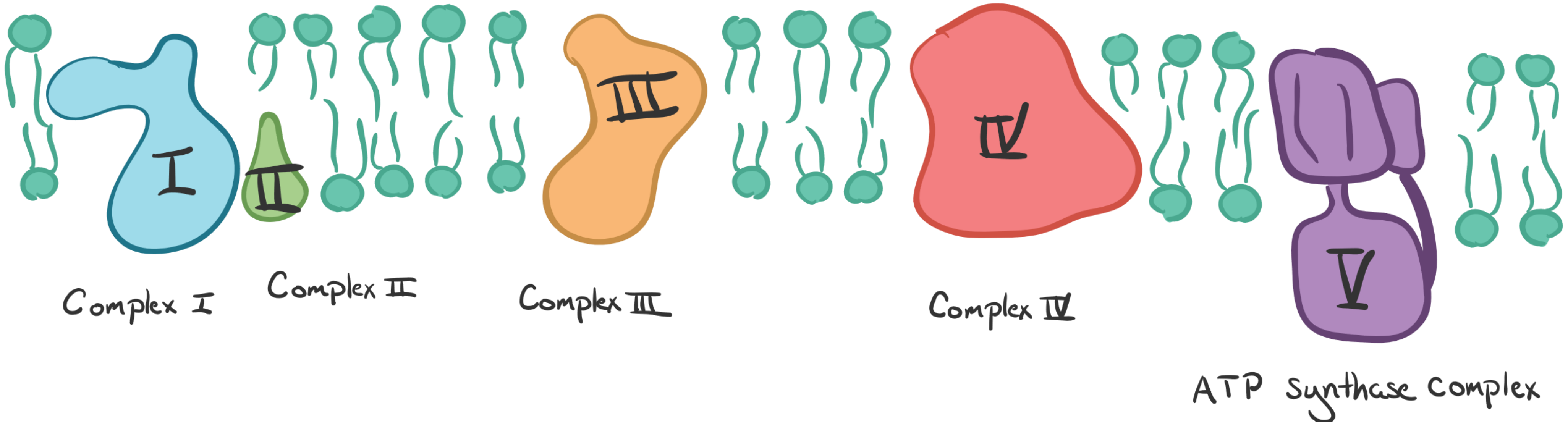
- We also made $NADH_2$ and FADH
  - These travel to the inner membrane of the mitochondria, where they help to fuel the next step
    - The electron transport chain

The Electron Transport Chain

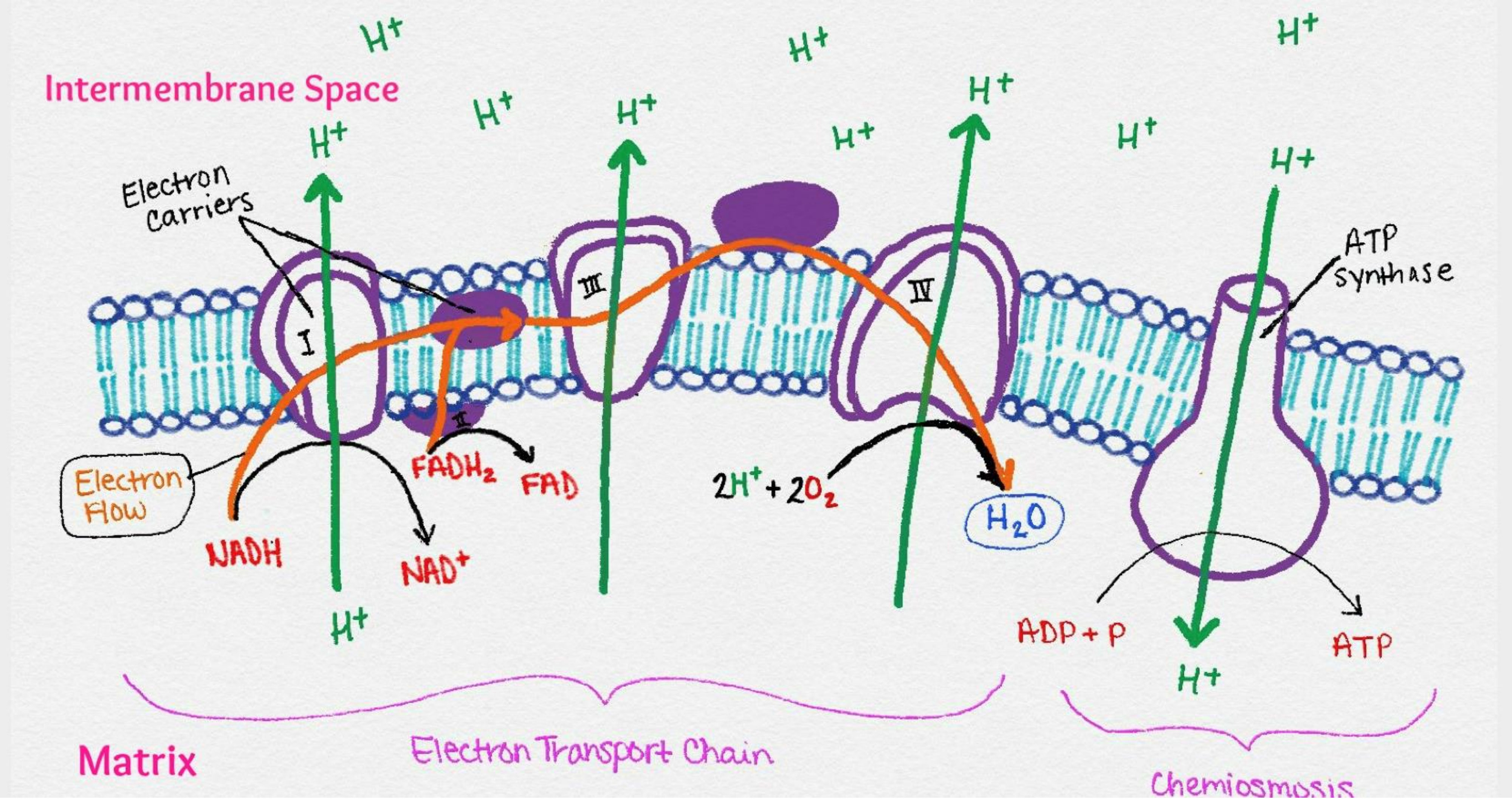
- A series of oxidation (loss of electrons) and reduction (gain electrons) reactions
  - Shortened Redox (sometimes RedOx)
- This moves electrons down an energy gradient (from high to low) down to a final receptor
  - Oxygen

The Electron Transport Chain

- As the electrons move down the gradient, enzymes work to form ATP



The Electron Transport Chain



The Electron Transport Chain

- We had 10 NADH and 2 FADH formed from each glucose molecule

- Each $NADH_2$ molecule yields 3 ATP molecules
- Each FADH molecule yields 2 ATP molecules

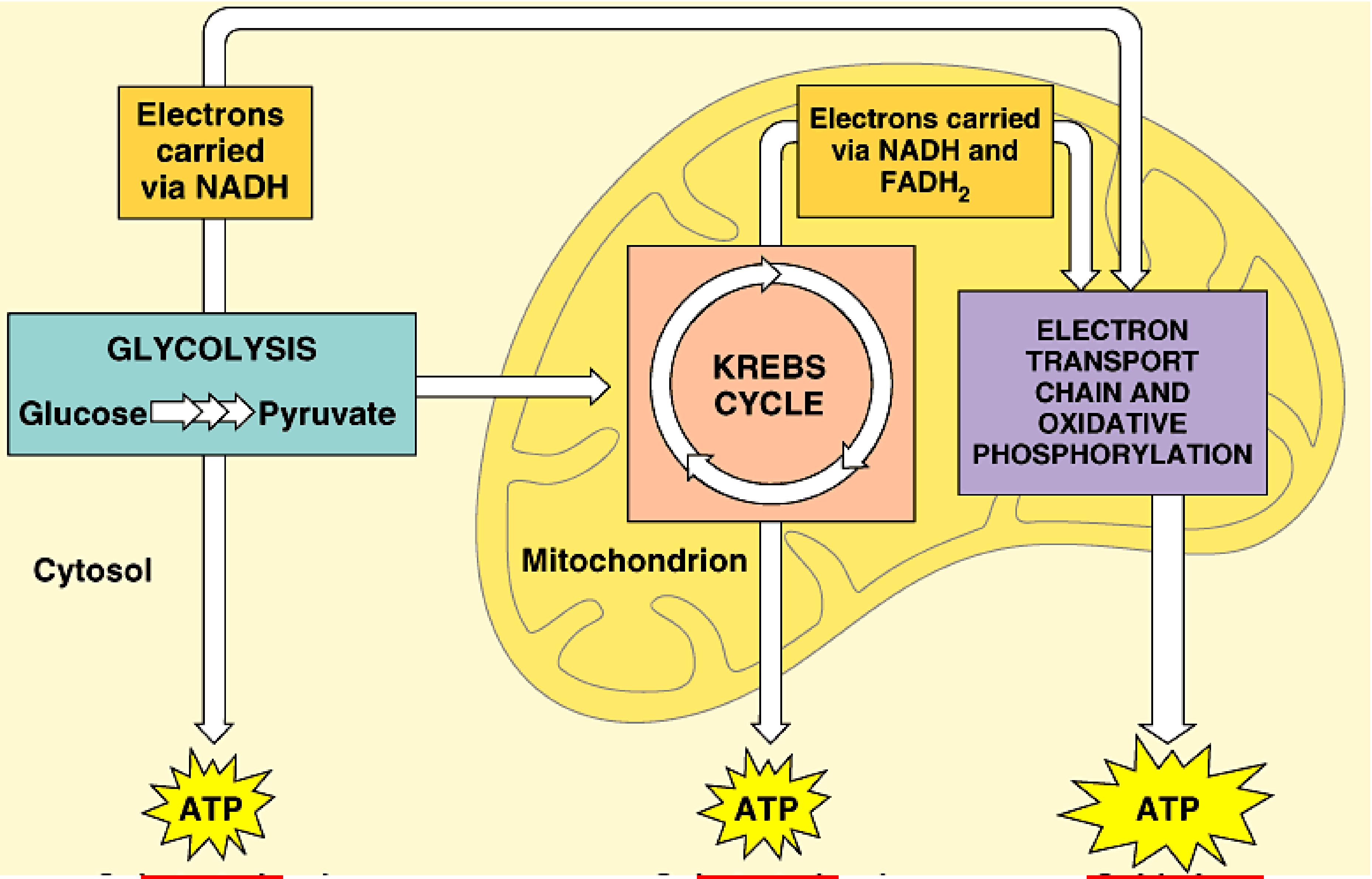
- A total of 34 ATP molecules are formed

The Electron Transport Chain

- We didn’t “spend” anymore ATP
- And we produced 34 ATP

- Net: 34 ATP

- **Total (so far): 38 ATP**



2 Net

2 Net

34 Net

Why do we need food and oxygen?

Why do we need food and oxygen?

- We need food for the glucose.
- We need oxygen because oxygen is the final ion receptor in the electron transport chain
  - This is what allows us to produce the ATP

Yet…

- We are able to function for short periods of time without oxygen

Anaerobic Respiration

- Anaerobic respiration is respiration that takes place when oxygen is in short supply
  - Takes place in
    - Animal cells
    - Some unicellular organisms

- There are two types
  - Lactic Acid Fermentation
  - Alcoholic Fermentation

Anaerobic Respiration

- Anaerobic respiration is not efficient
  - Most of the energy does NOT go to ATP
    - It stays in the byproducts – lactic acid or alcohol

Lactic Acid Fermentation

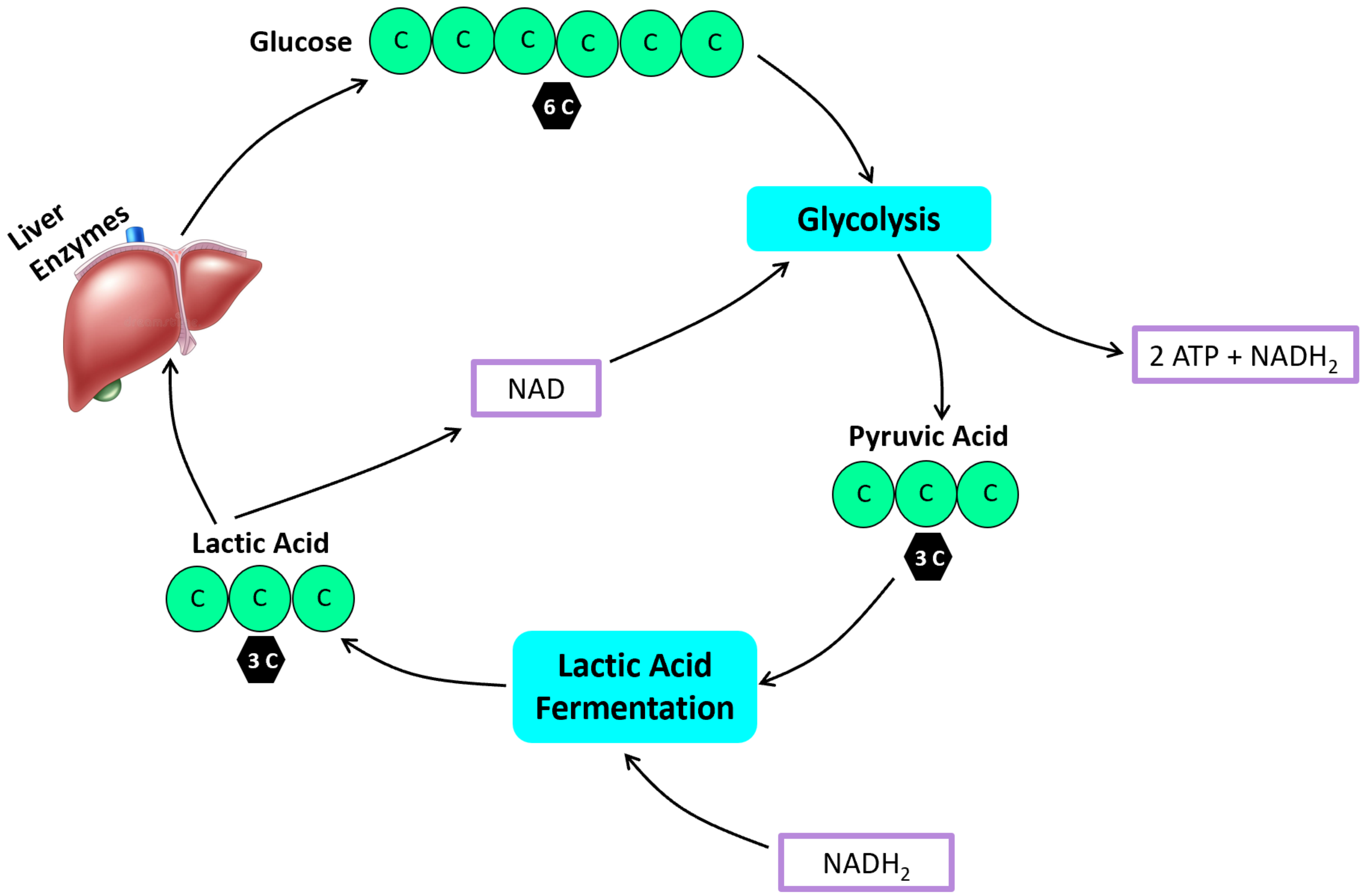
- When oxygen becomes scarce, the $NADH_2$ donates it's hydrogen to pyruvic acid
  - This produces lactic acid

Lactic Acid Fermentation

- Think about when you exercise really hard and/or for a long time
  - You start to feel that sharp pain in your side
  - Your muscles start to burn a bit

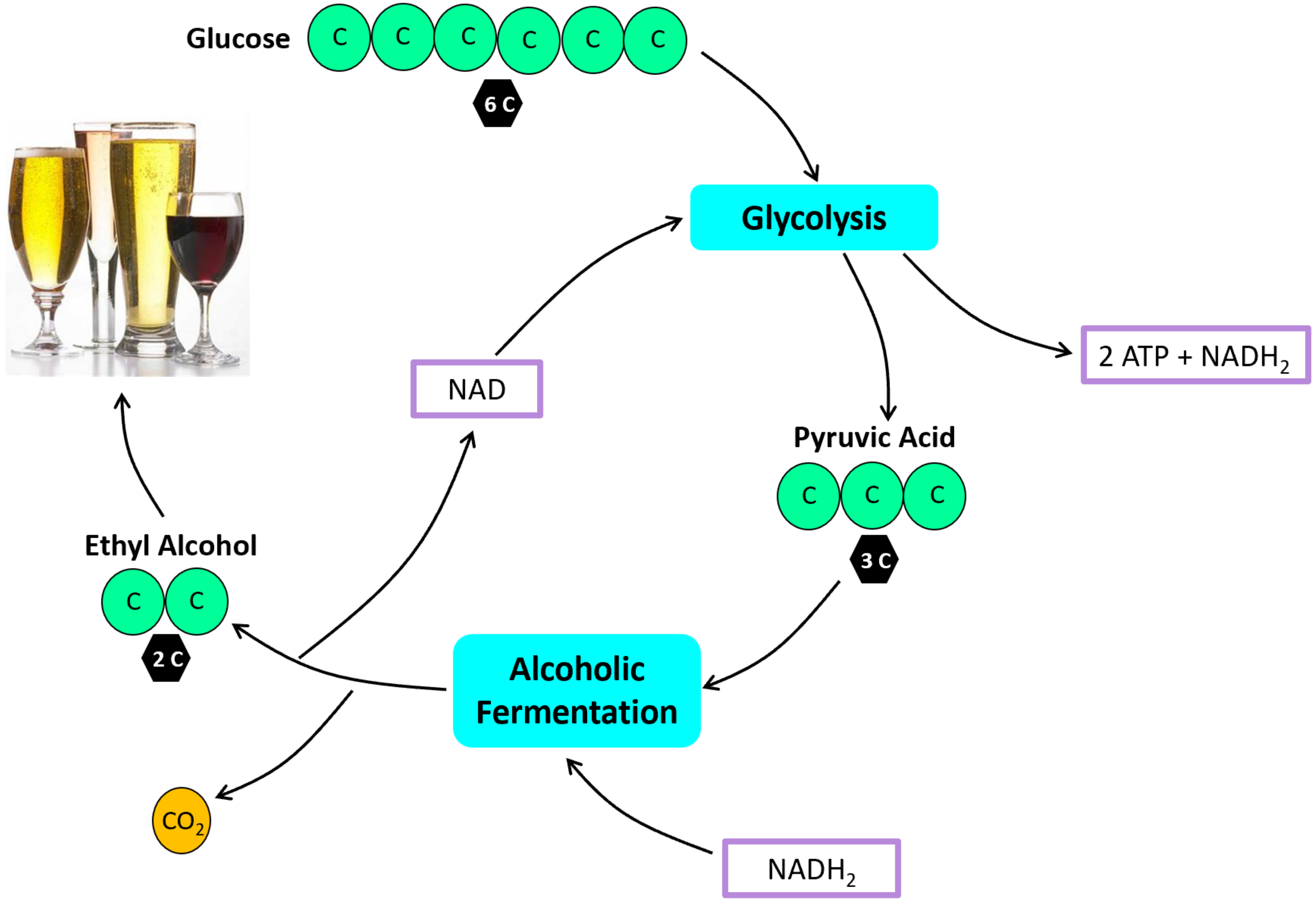
Lactic Acid Fermentation

- When you exercise, you use most of your body's free oxygen
  - Your body will switch to lactic acid fermentation
    - It is the build up of lactic acid that causes the burning in your muscles
- After resting, your circulatory system carries the lactic acid to the liver
  - The liver convers lactic acid to glucose
    - Where it can re-enter glycolysis


Glucose
C C C C C C
6 C
Glycolysis
2 ATP + NADH$_2$
Pyruvic Acid
C C C
3 C
Lactic Acid Fermentation
NADH$_2$
Lactic Acid
C C C
3 C
NAD
Liver Enzymes

Alcoholic Fermentation

- When oxygen is depleted, pyruvic acid can be converted to ethyl alcohol
- This is the process that makes beer and wine.
  - Alcohol content is limited by the fact that alcohol kills the organism (yeast!) producing it
    - Alcohol is a toxin



Glucose
C C C C C C
6 C
Glycolysis
2 ATP + $NADH_2$
NAD
Pyruvic Acid
C C C
3 C
Ethyl Alcohol
C C
2 C
Alcoholic Fermentation
CO_2
$NADH_2$

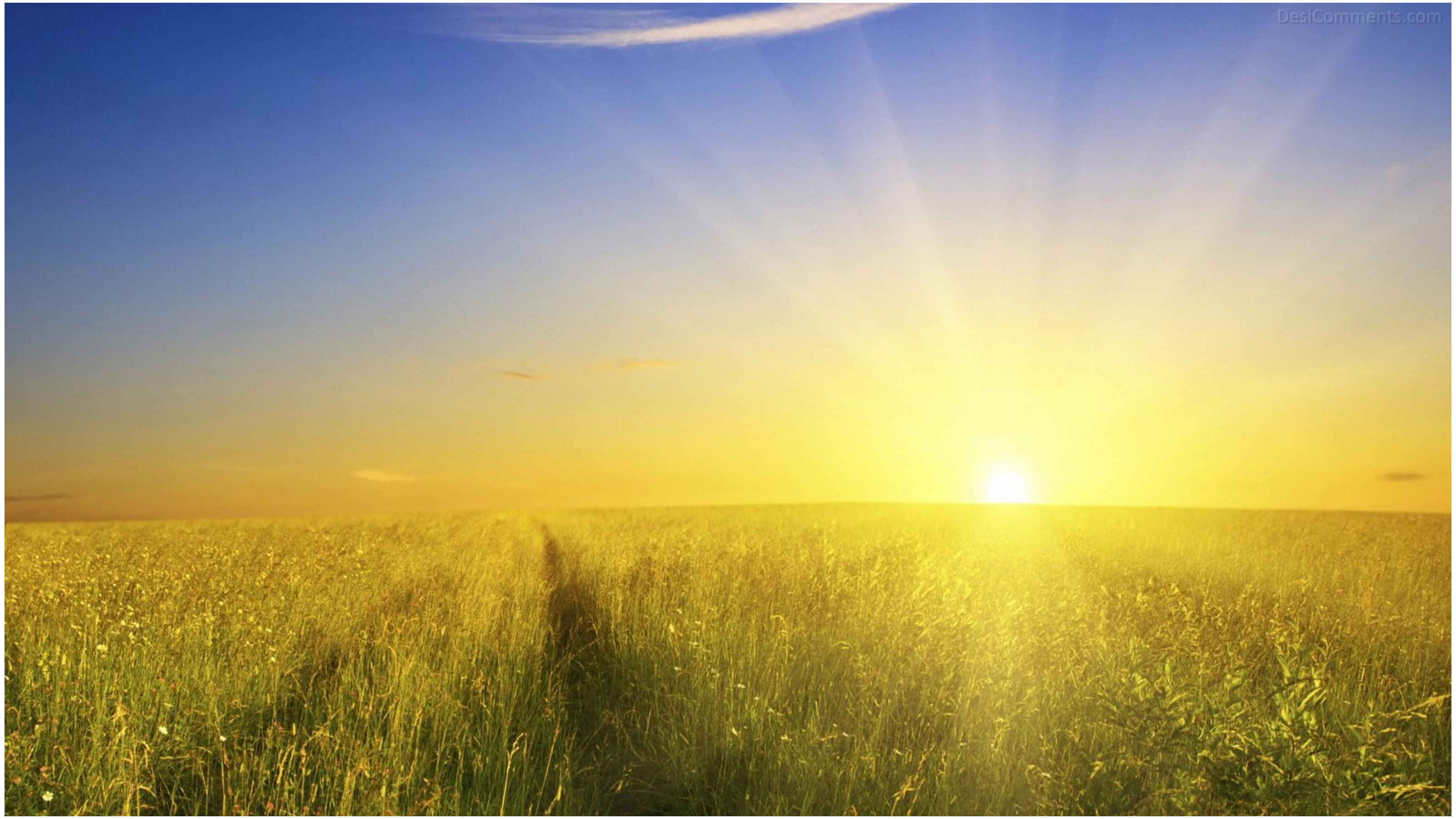
Respiration Overview

- Respiration – the breakdown of glucose with oxygen into energy to make ATP; byproducts are water and carbon dioxide
  - Why do we need to eat?
    - Glucose
      - Energy for the synthesis of ATP that is stored in the bonds of glucose
  - Why do we breathe?
    - Oxygen
      - Oxygen is used as the last ion receptor in the electron transport chain that allows us to produce ATP

Where do we get glucose and oxygen?

Where do we get glucose and oxygen?

- Plants
  - Plants utilize the energy in sunlight to take carbon dioxide and water and form glucose and oxygen

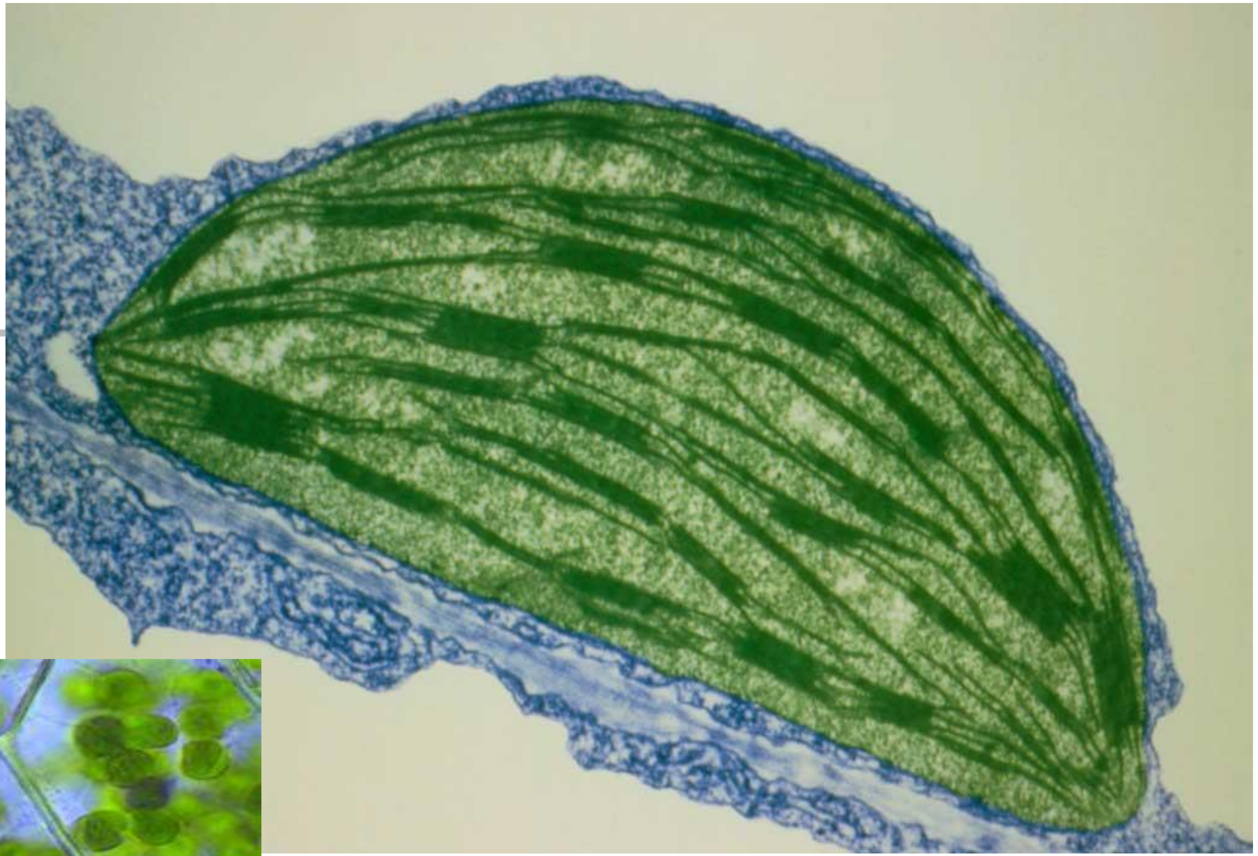


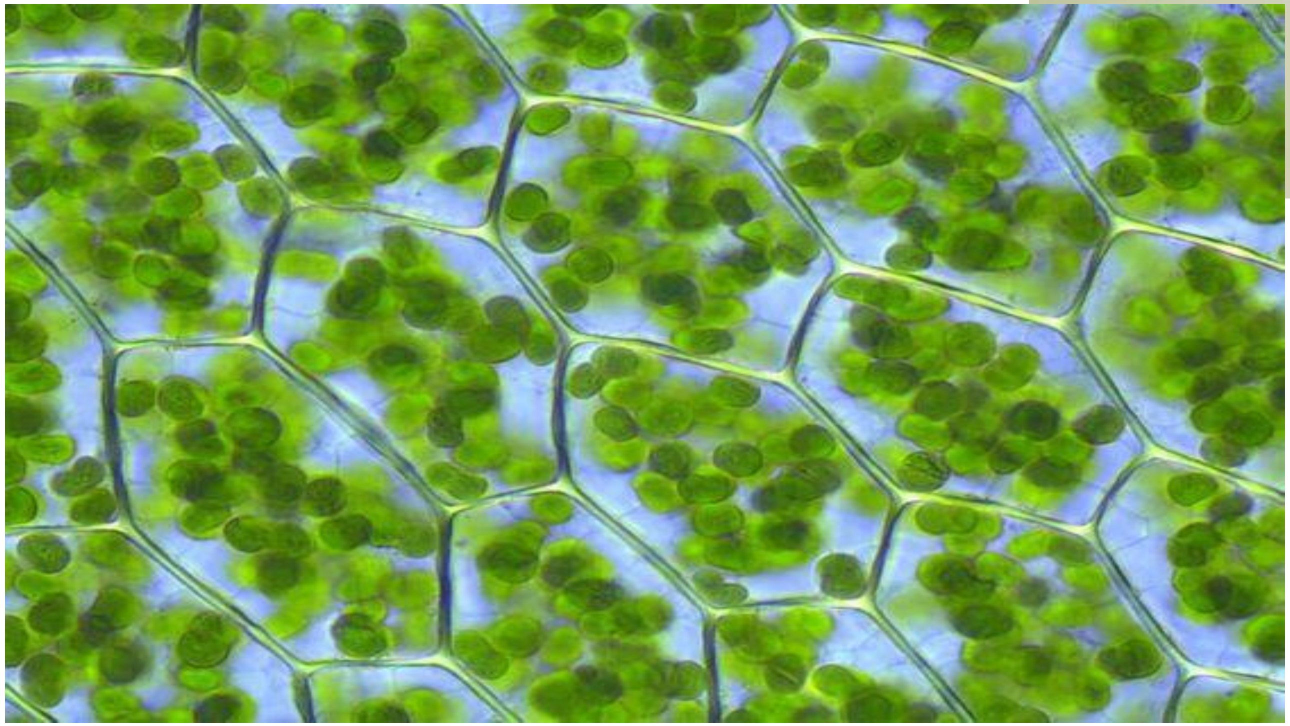
PHOTOSYNTHESIS

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

Photosynthesis

- Photosynthesis takes place in chloroplasts



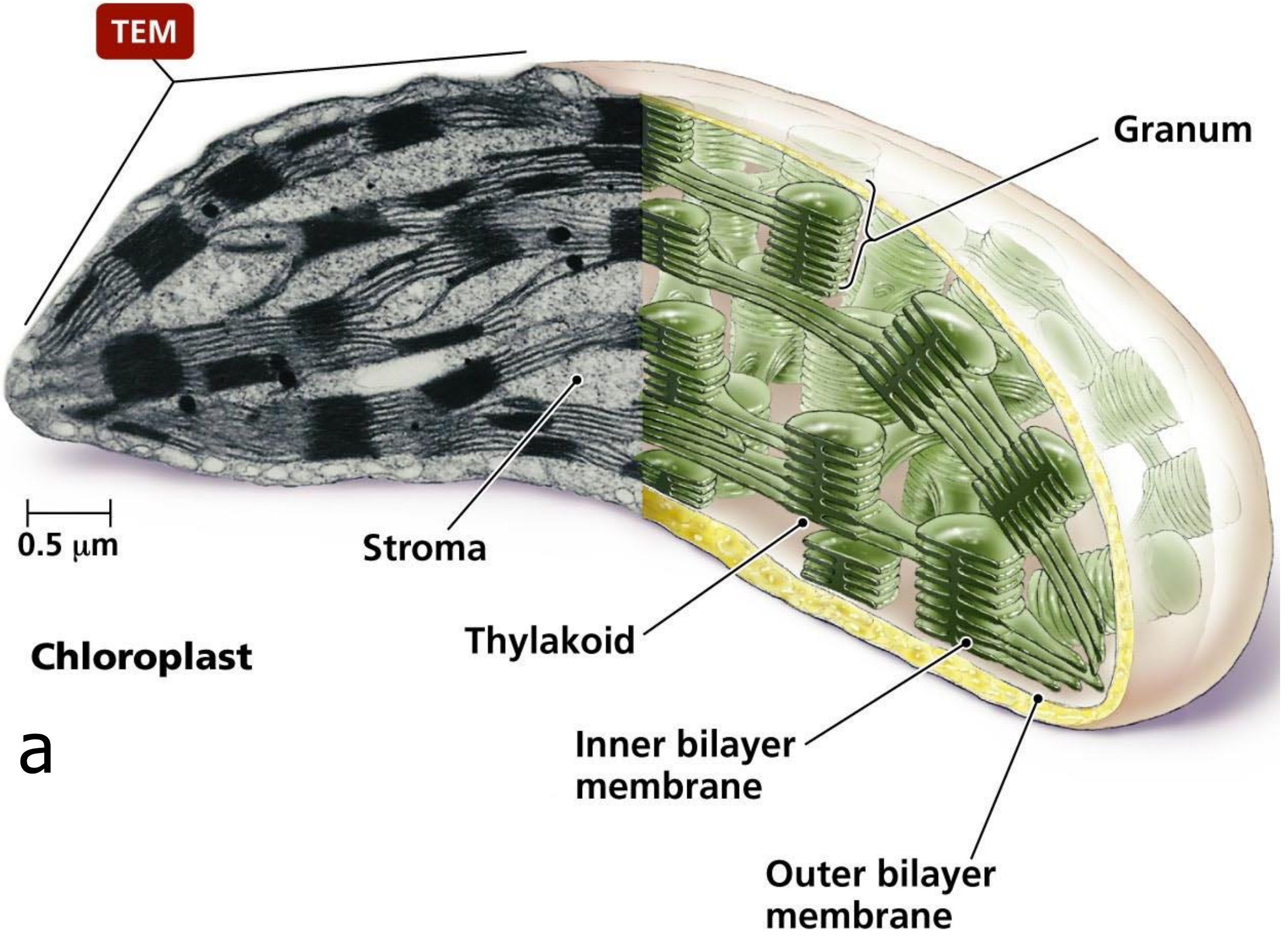


Chloroplasts

- Scientists believe that chloroplasts and mitochondria were once organisms that lived in larger cells in a symbiotic relationship
  - Over time, the larger cells incorporated the DNA of the organisms that could make food and release energy
    - Resulting in the organelles we know as chloroplasts and mitochondria

Chloroplasts

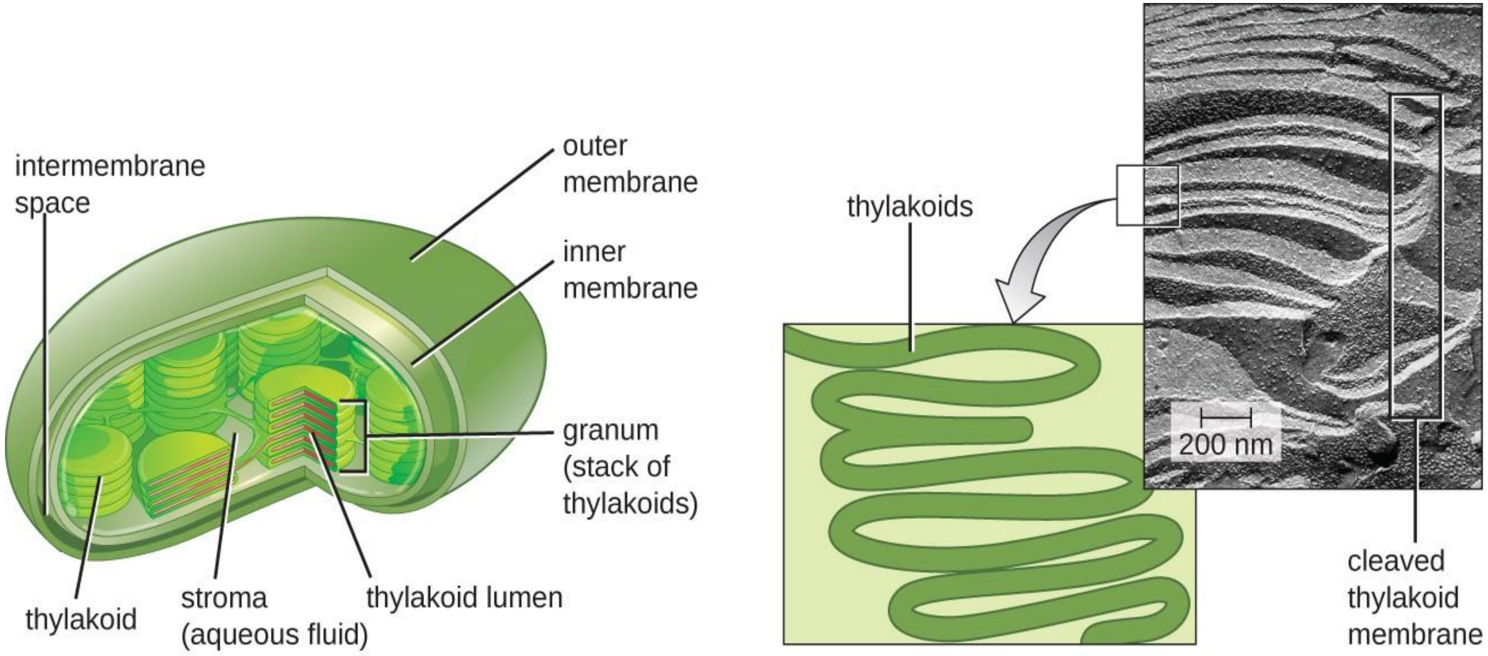
- Surrounded by a double membrane
- Interior membrane is arranged in stacks of photosynthetic membranes called thylakoids
  - A stack of thylakoids is called a granum



Chloroplasts

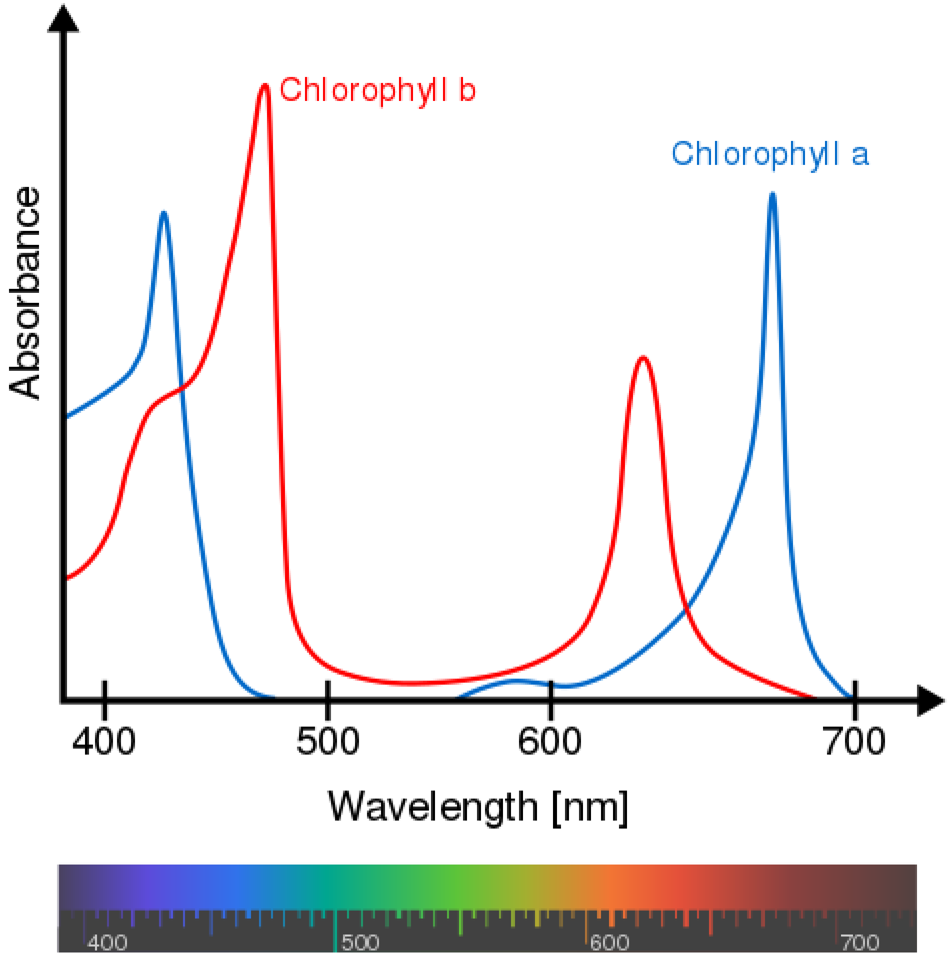
- Inside of each thylakoid is a reservoir called a lumen.

- Thylakoids are surrounded by a protein rich substance called the stroma.



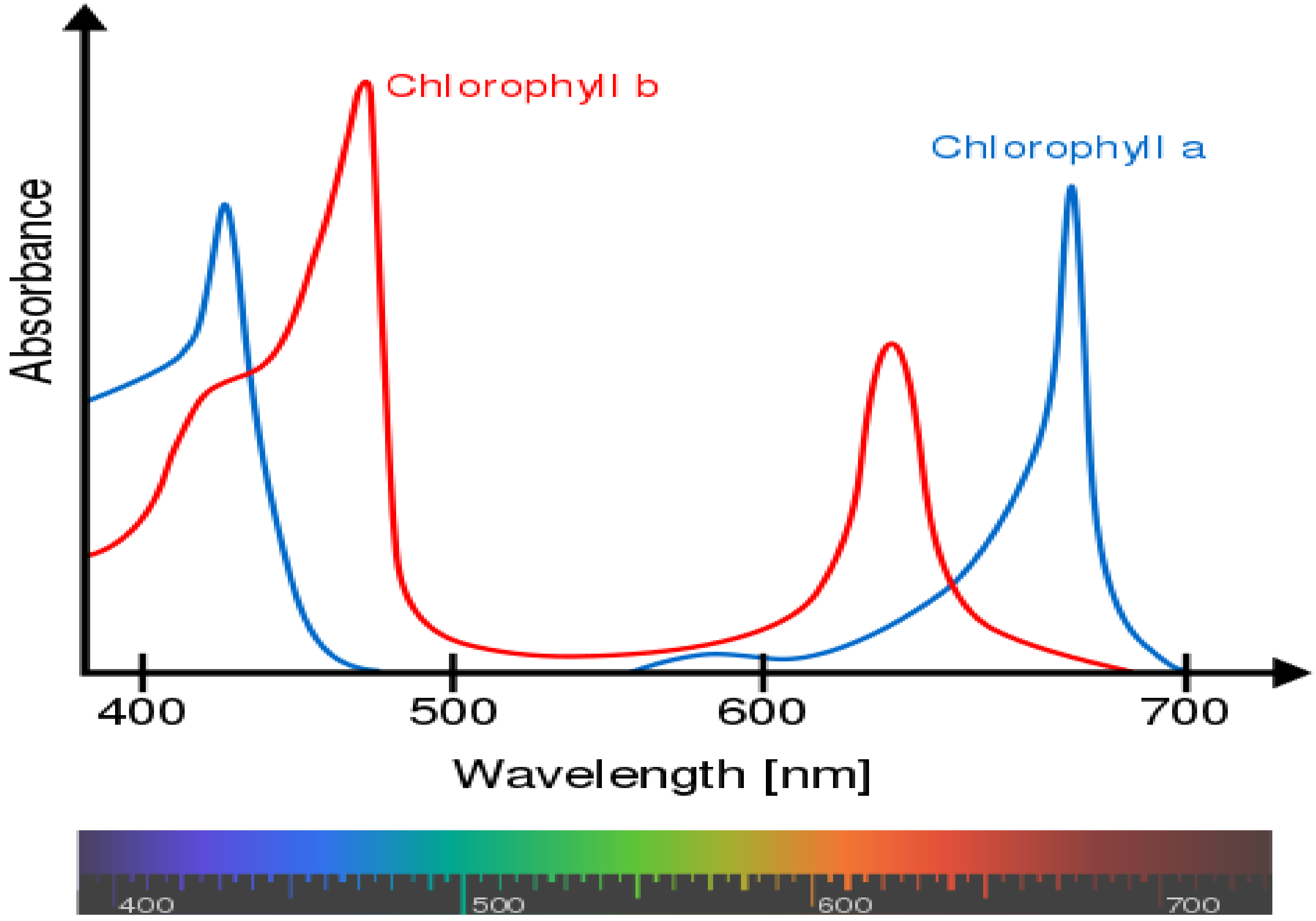
Photosynthetic Pigments

- The primary photosynthetic pigment is chlorophyll
  - Pigments absorb light
- Chlorophyll absorbs all colors except green



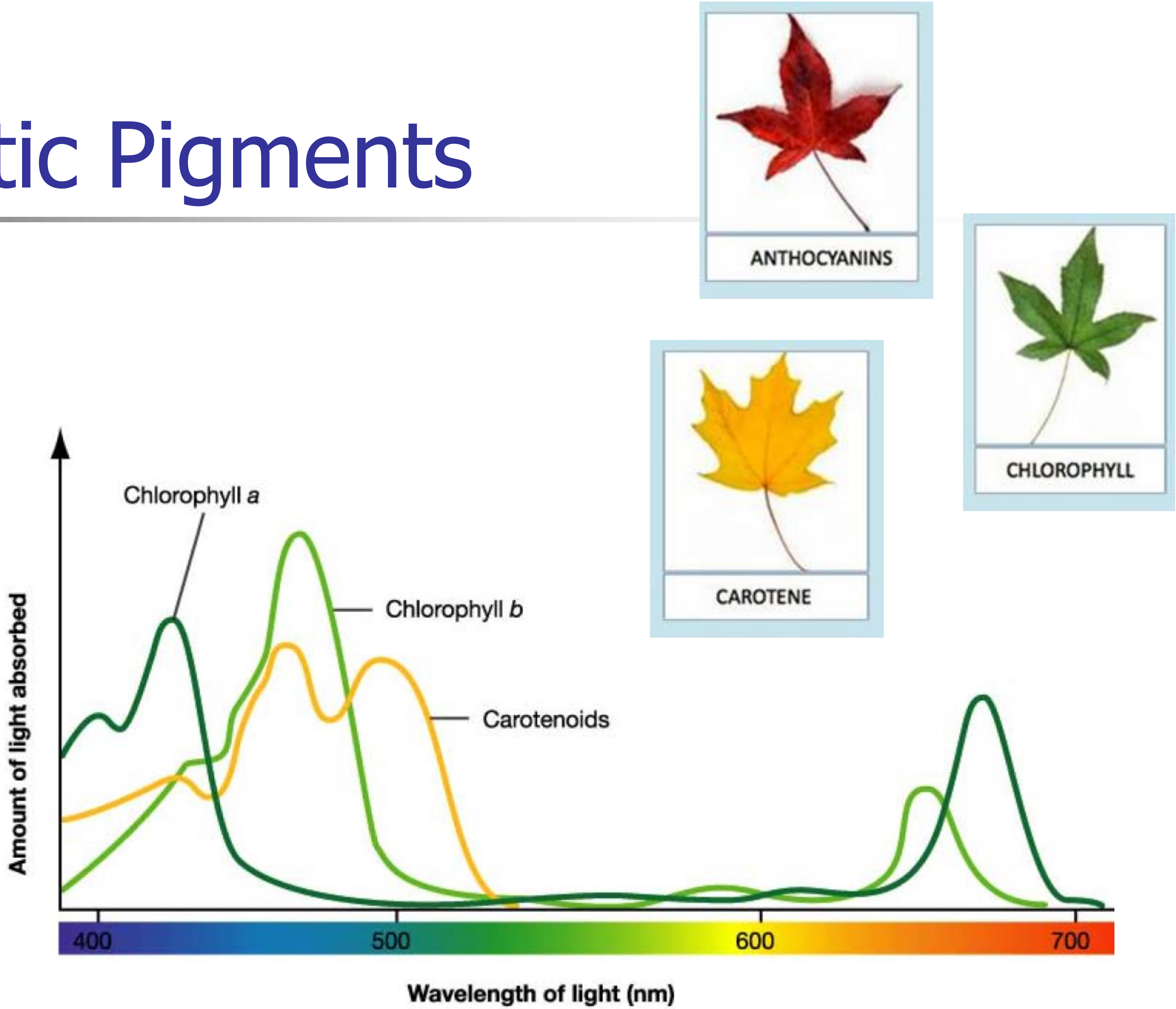
Photosynthetic Pigments

- There are five types of chlorophyll that absorb slightly different ranges of light
  - a, b, c, d, and bacteriochlorophyll
    - Chlorophyll a and b are the most common



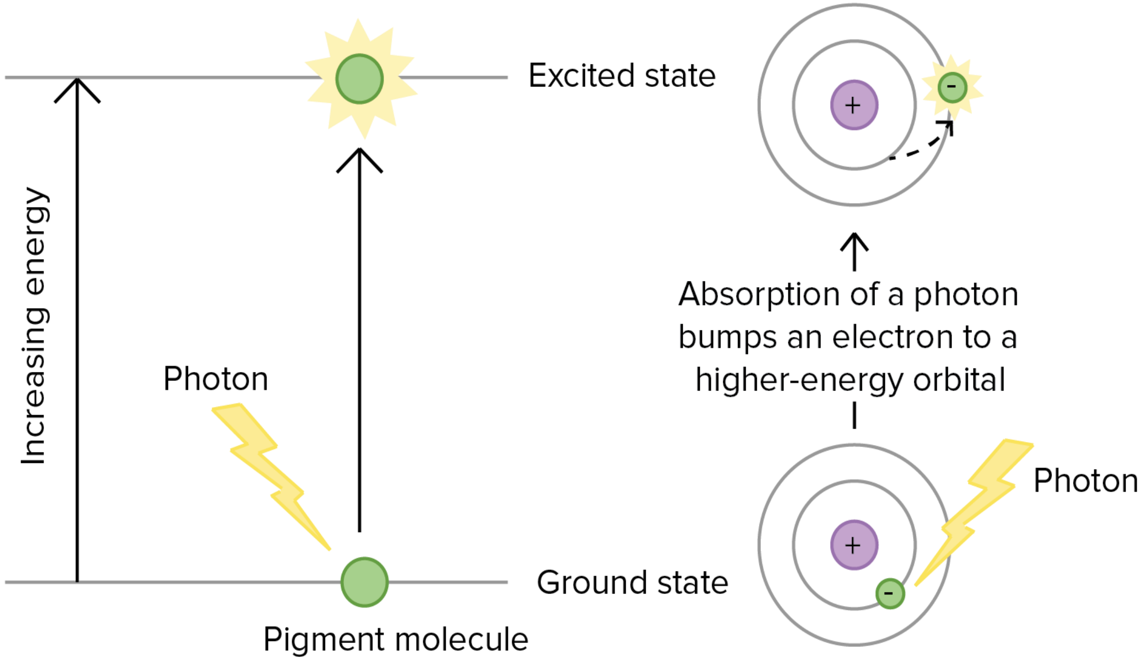
Photosynthetic Pigments

- There are other accessory pigments.
  - Carotenoids are yellow, orange and brown
    - Carotenes are orange
    - Xanthophylls are brown
    - Phycobilins are red and/or blue
      - Found in algae



Light

- Light is a type of energy that travels in a wave
  - When it hits certain molecules, it can move the electron levels from a lower energy level to a higher energy level

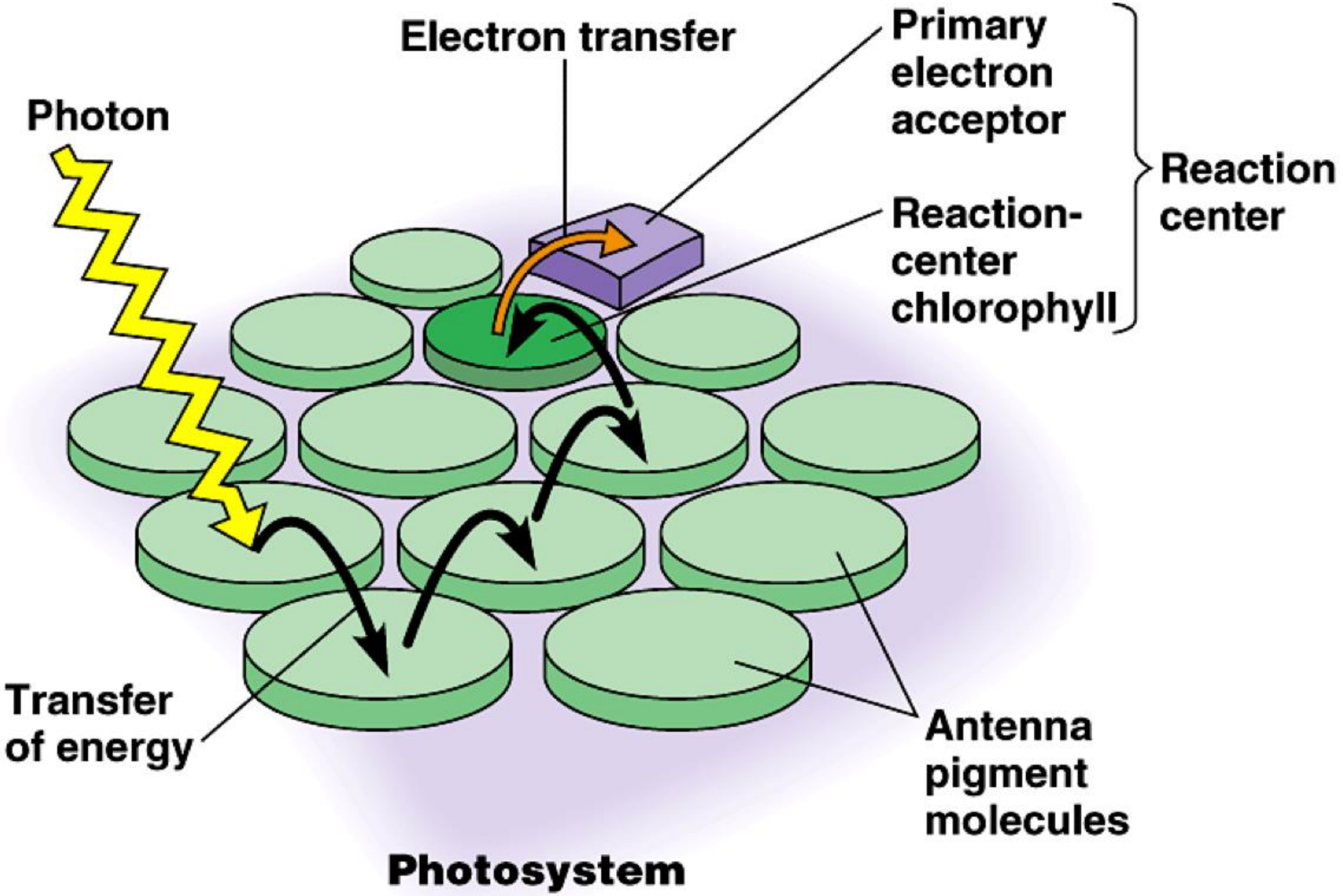


Two Reactions

- There are two reactions in photosynthesis.
  - The Light Reaction
    - MUST have light to take place
  - The Dark Reaction
    - Does not have to have light to take place

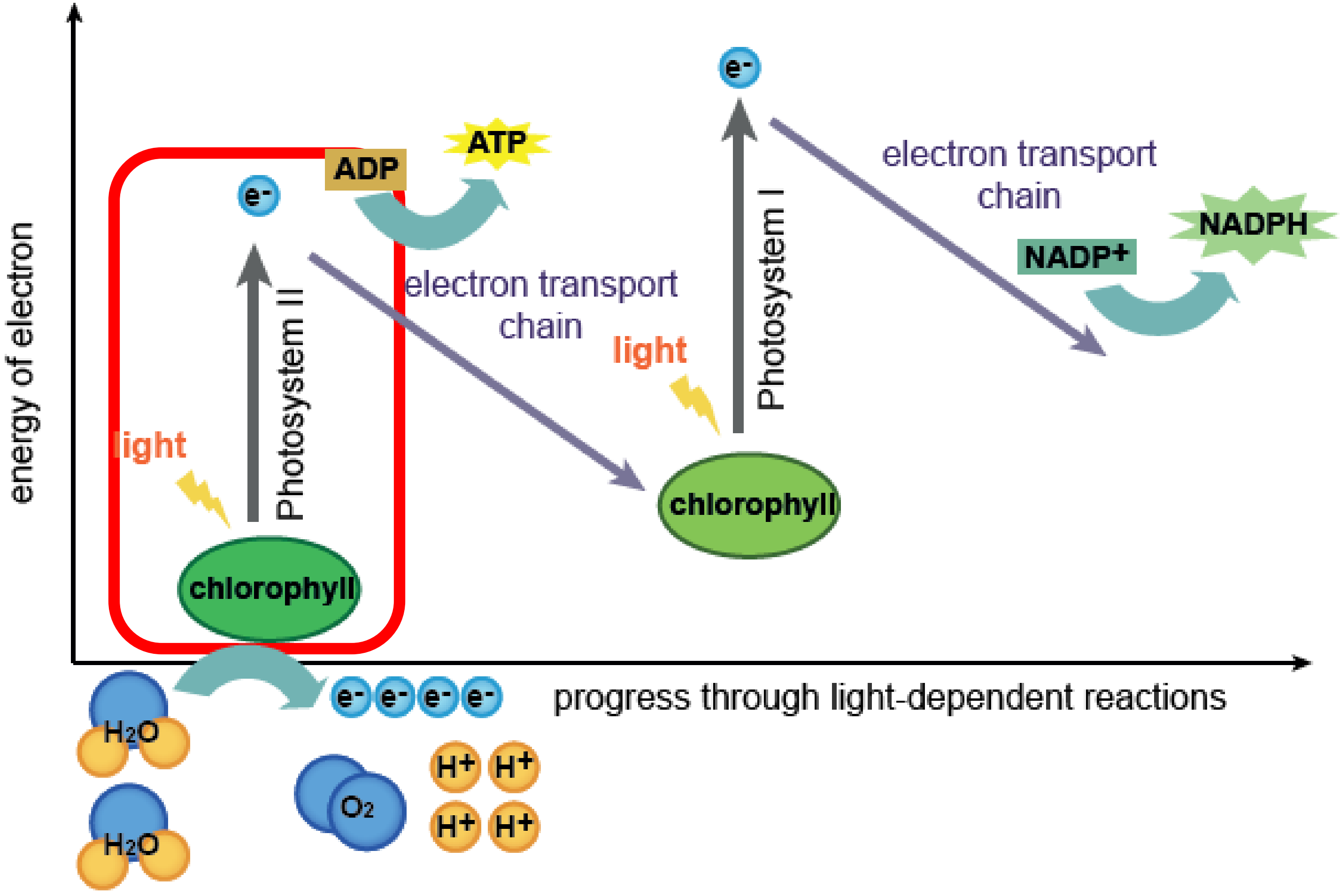
The Light Reaction

- The light reaction takes place in two photosystems
  - Photosystem I
  - Photosystem II



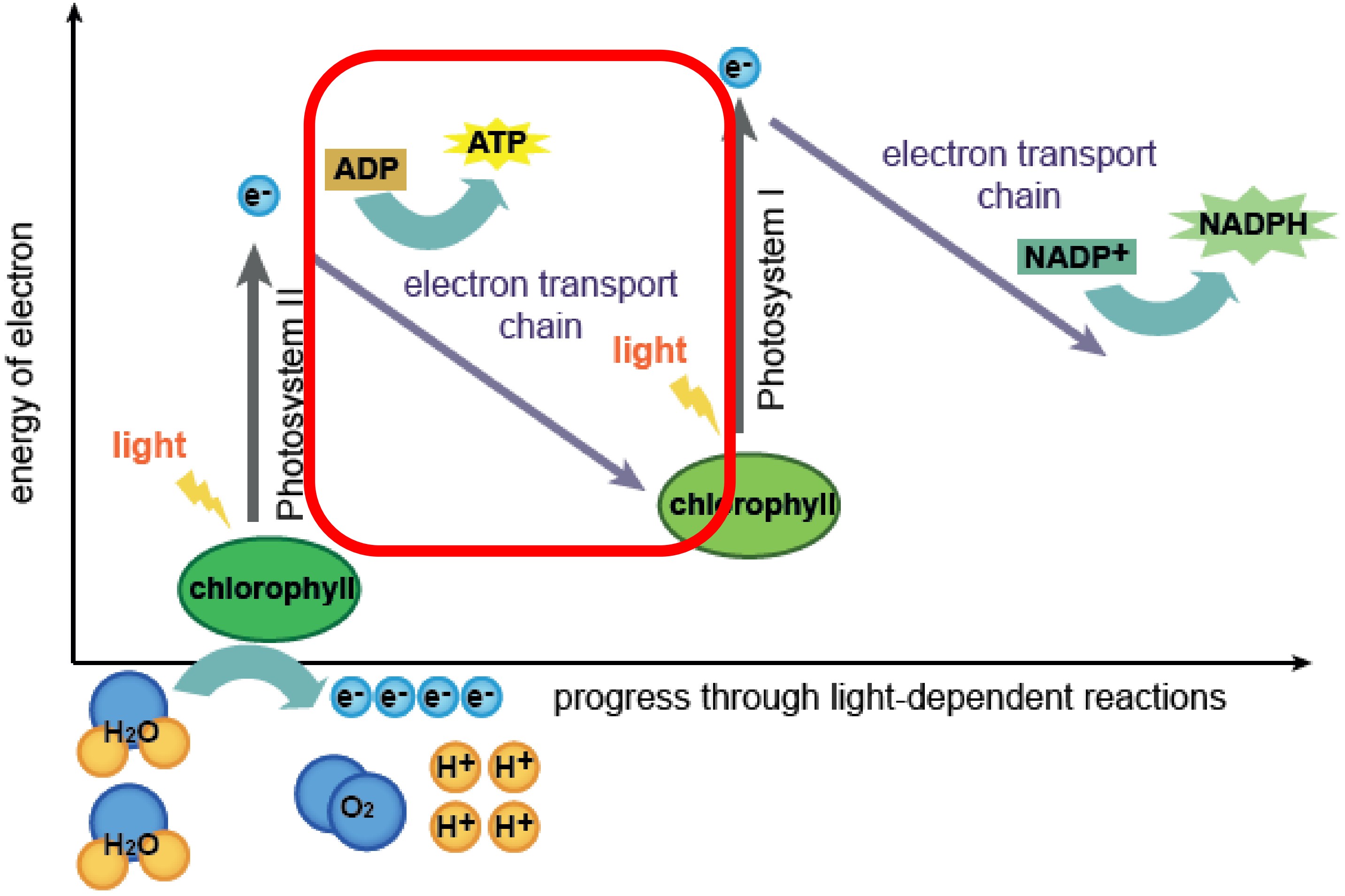
The Light Reaction

- When light hits photosystem II, it causes electrons to be lost from the molecule chlorophyll.



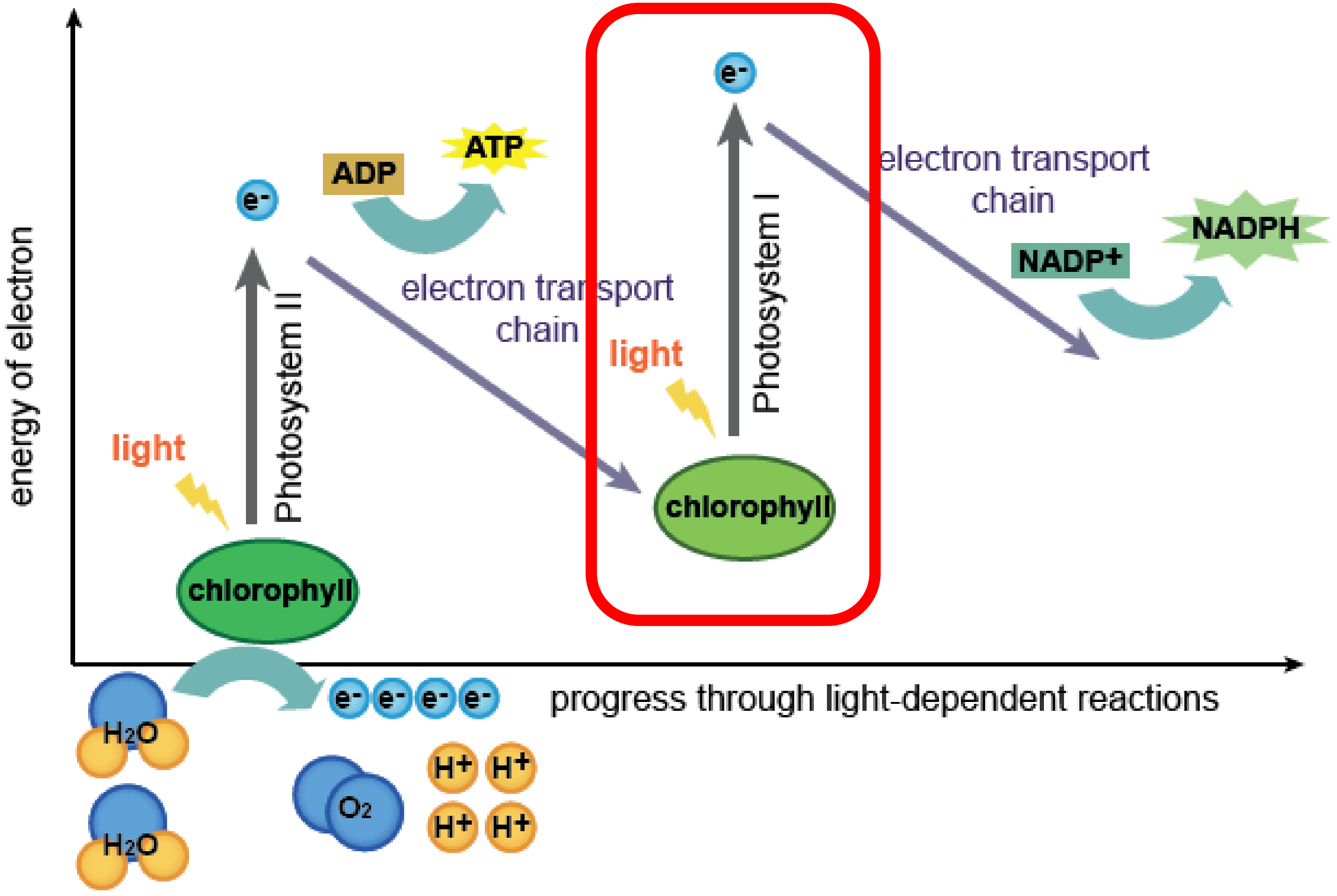
The Light Reaction

- This electron is passed from molecule to molecule
  - This series of molecules is called the electron chain



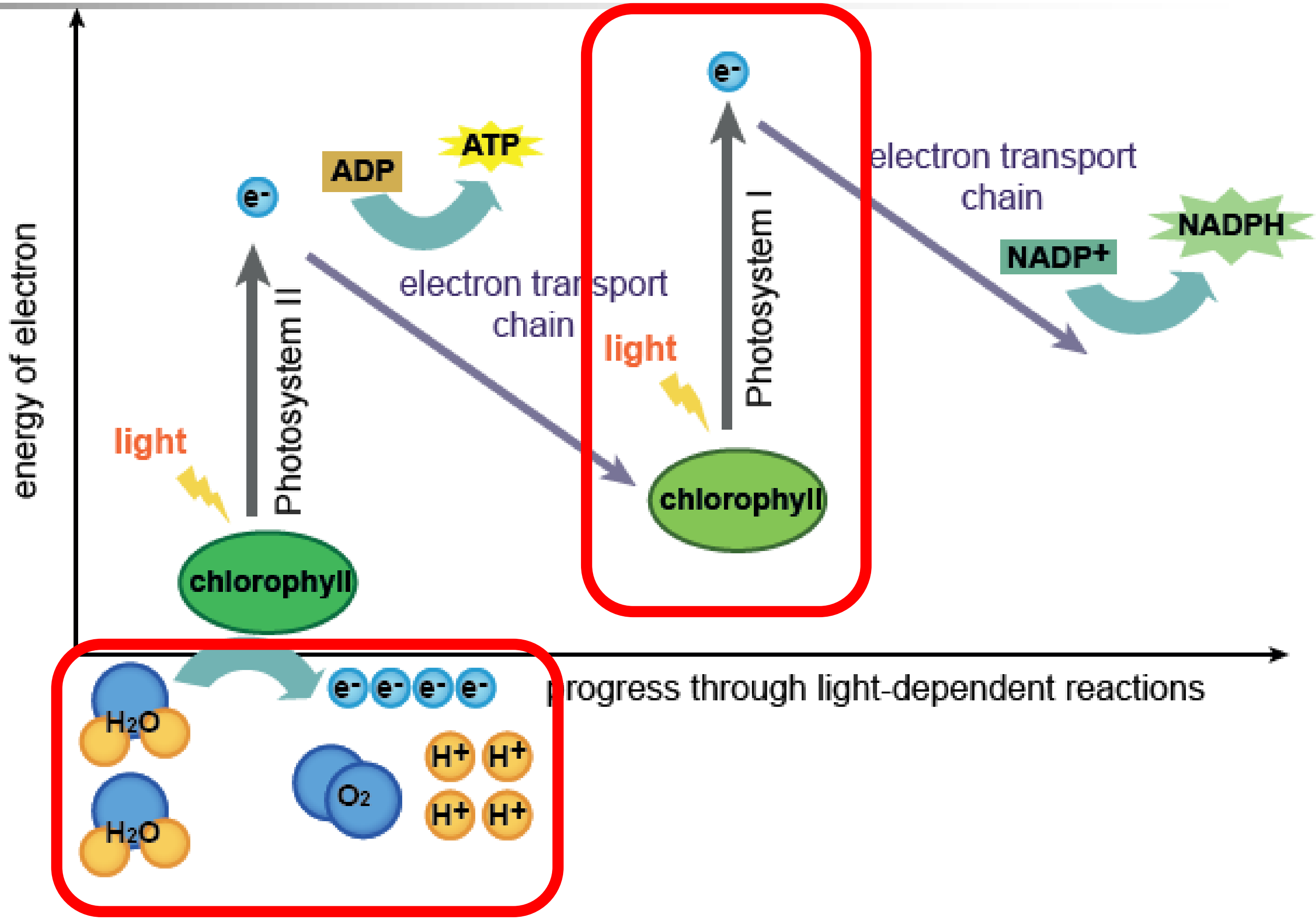
The Light Reaction

- After the electrons have traveled through the electron transport chain, finally photosystem I loses an electron



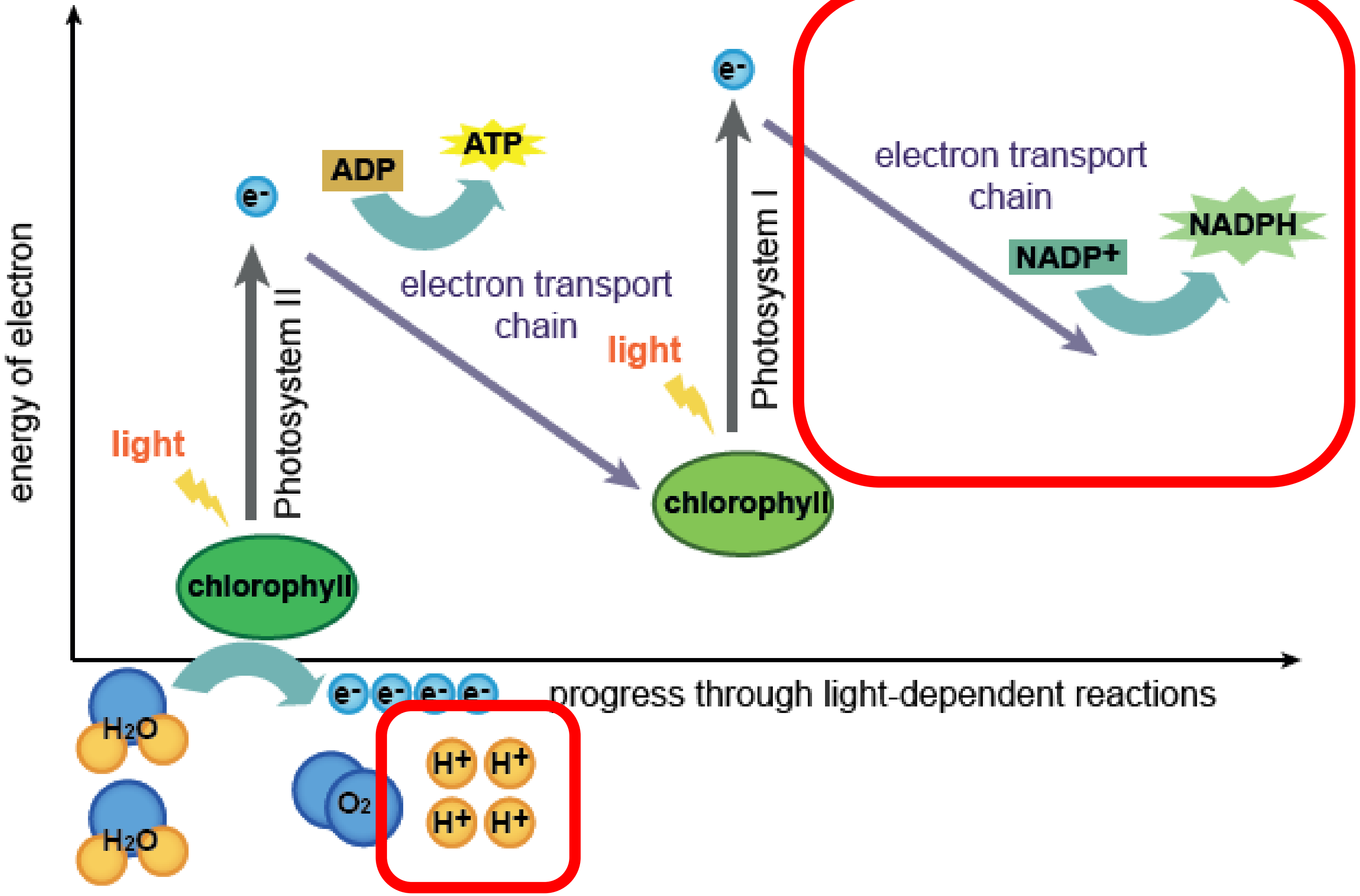
The Light Reaction

- Water is split
  - The hydrogen ions move to the lumen of the thylakoid.
  - The oxygen atom bonds with another oxygen atom and is released into the atmosphere.



The Light Reaction

- Electrons are then passed from molecule to molecule in another electron transport chain
  - Hydrogen bonds with $NADP^+$ to form NADPH



The Light Reaction (Review)

- Electrons are excited when struck by light.
- The electrons are transported down the electron transport chain.
- Water is the final donor for the hydrogen ions.
- Oxygen is released into the atmosphere.

Dark Reactions

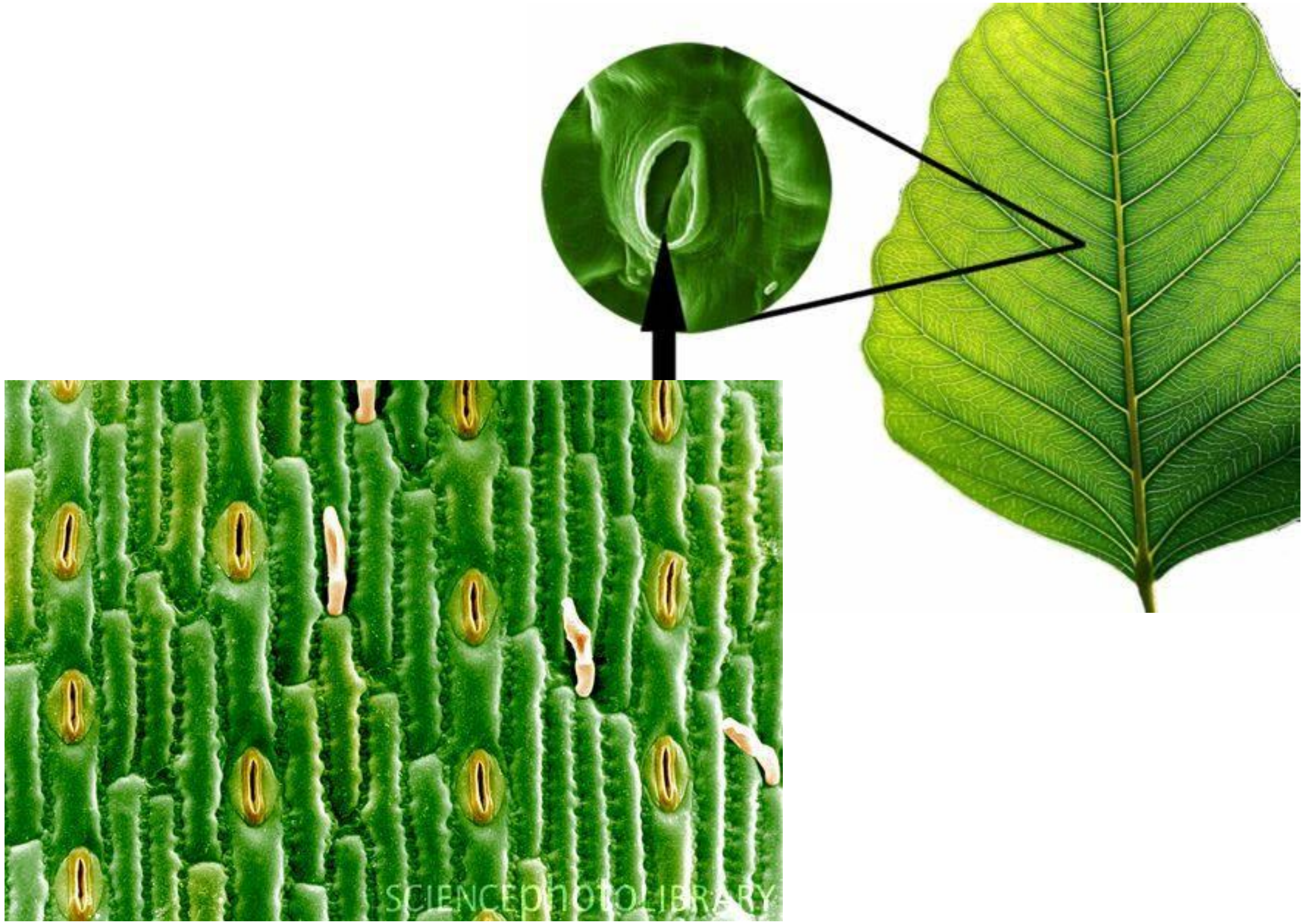
- Misconception
  - These reactions do not HAVE to take place in the dark, but they CAN

Dark Reactions

- Sometimes known as the Calvin cycle
  - After Melvin Calvin, the discoverer
- AKA the C_3 cycle

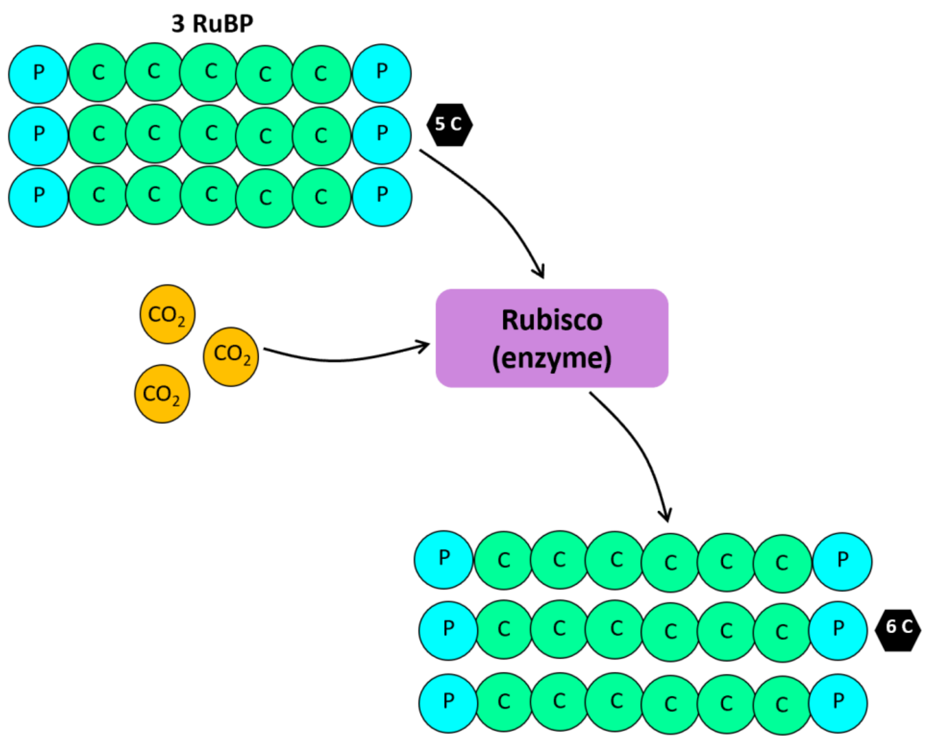
Dark Reactions / Calvin Cycle / C_3

- CO_2 enters the cell from the atmosphere through special pores called stomata



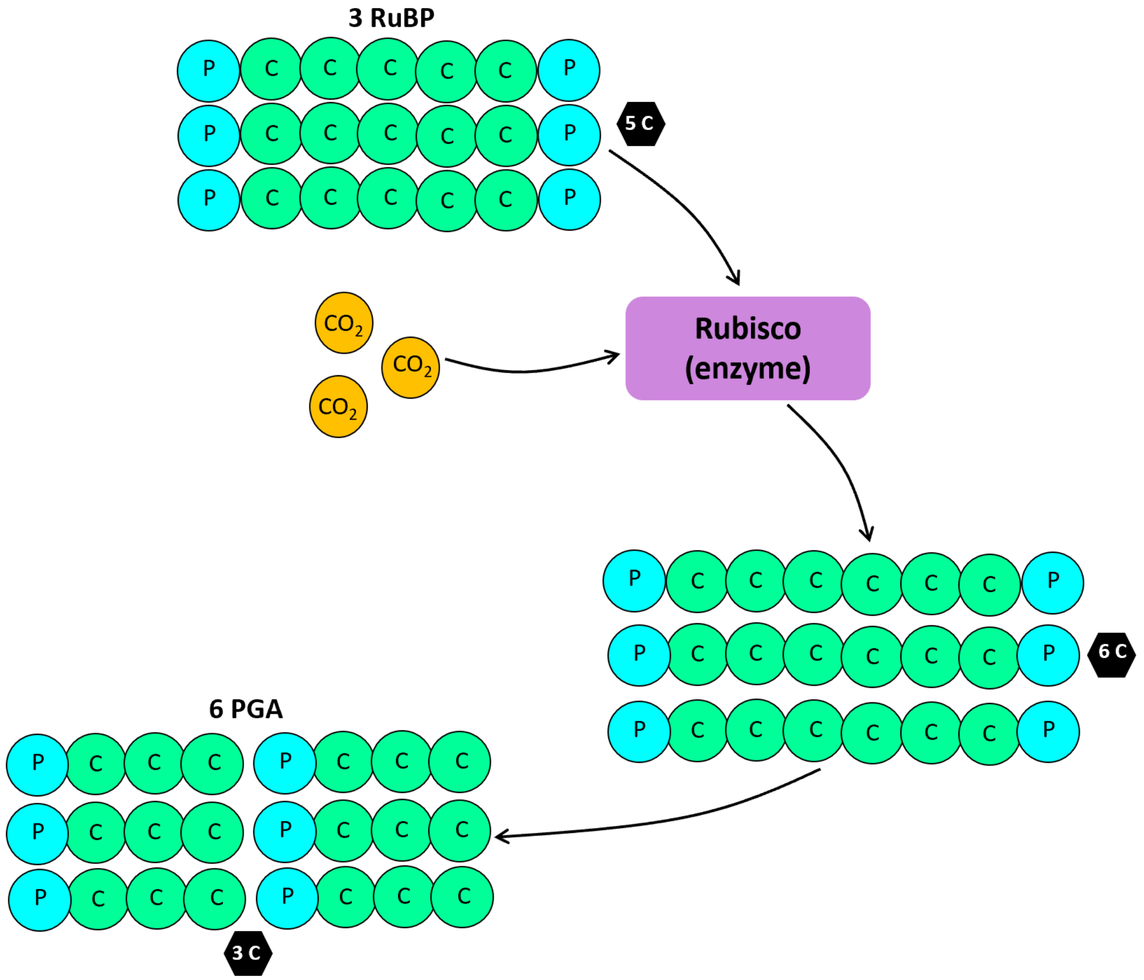
Dark Reactions / Calvin Cycle / C_3

- Carbon Fixation
  - RuBP, a 5-C molecule, bonds to the CO_2
- This CO_2 forms an unstable 6-C molecule



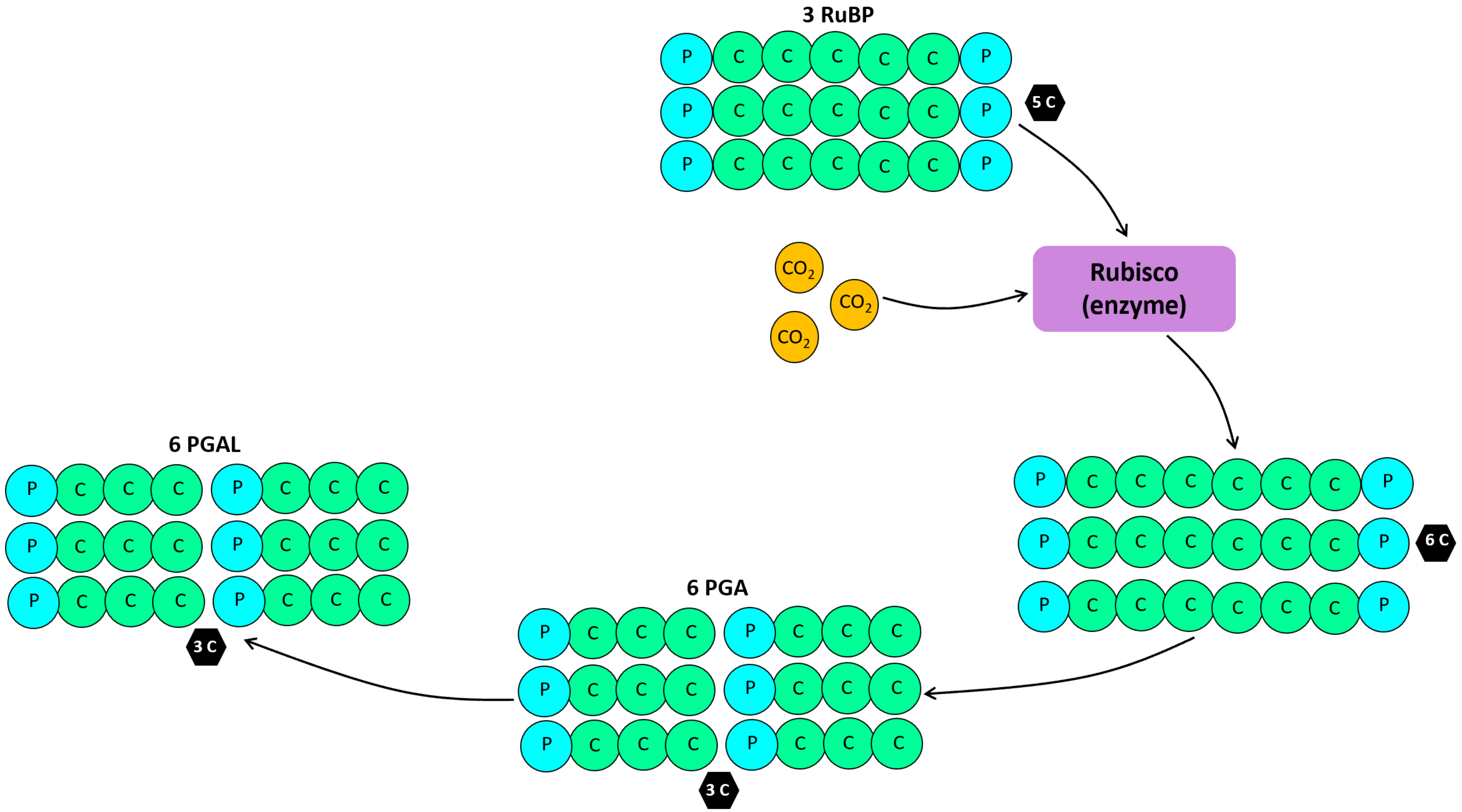
Dark Reactions / Calvin Cycle / C_3

- The unstable 6-Carbon molecule immediately splits into PGA



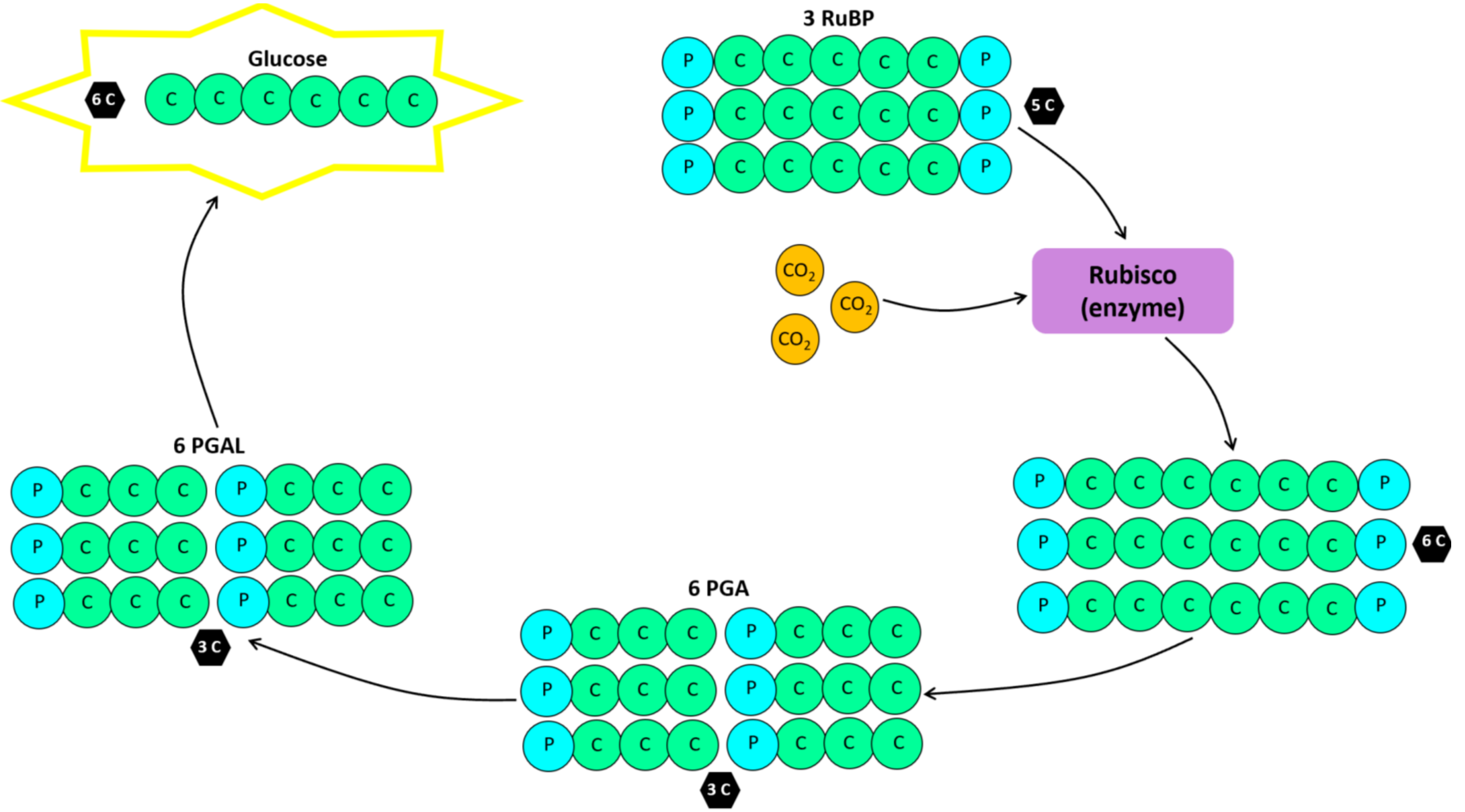
Dark Reactions / Calvin Cycle / C_3

- PGA is transformed into PGAL



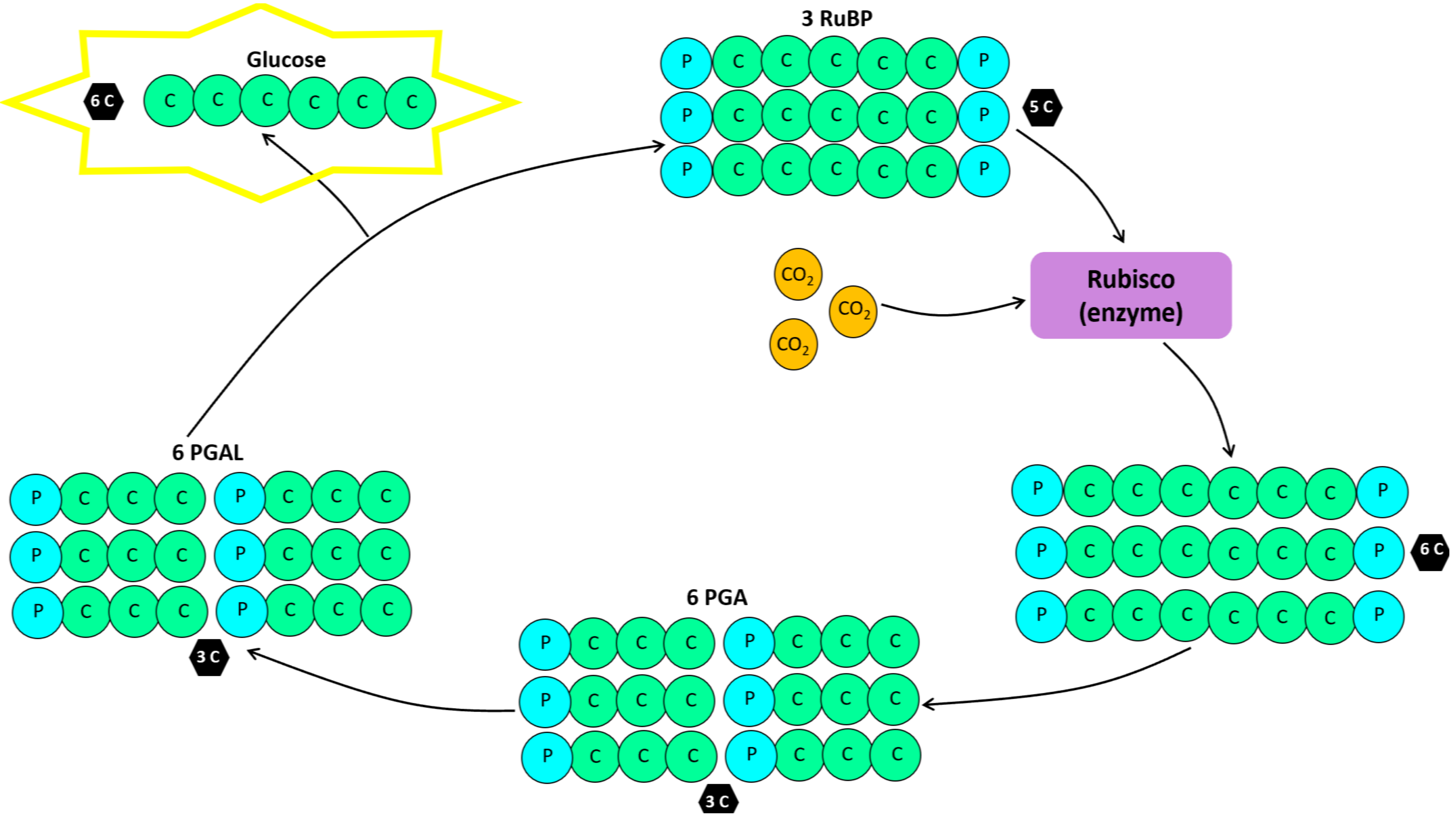
Dark Reactions / Calvin Cycle / C_3

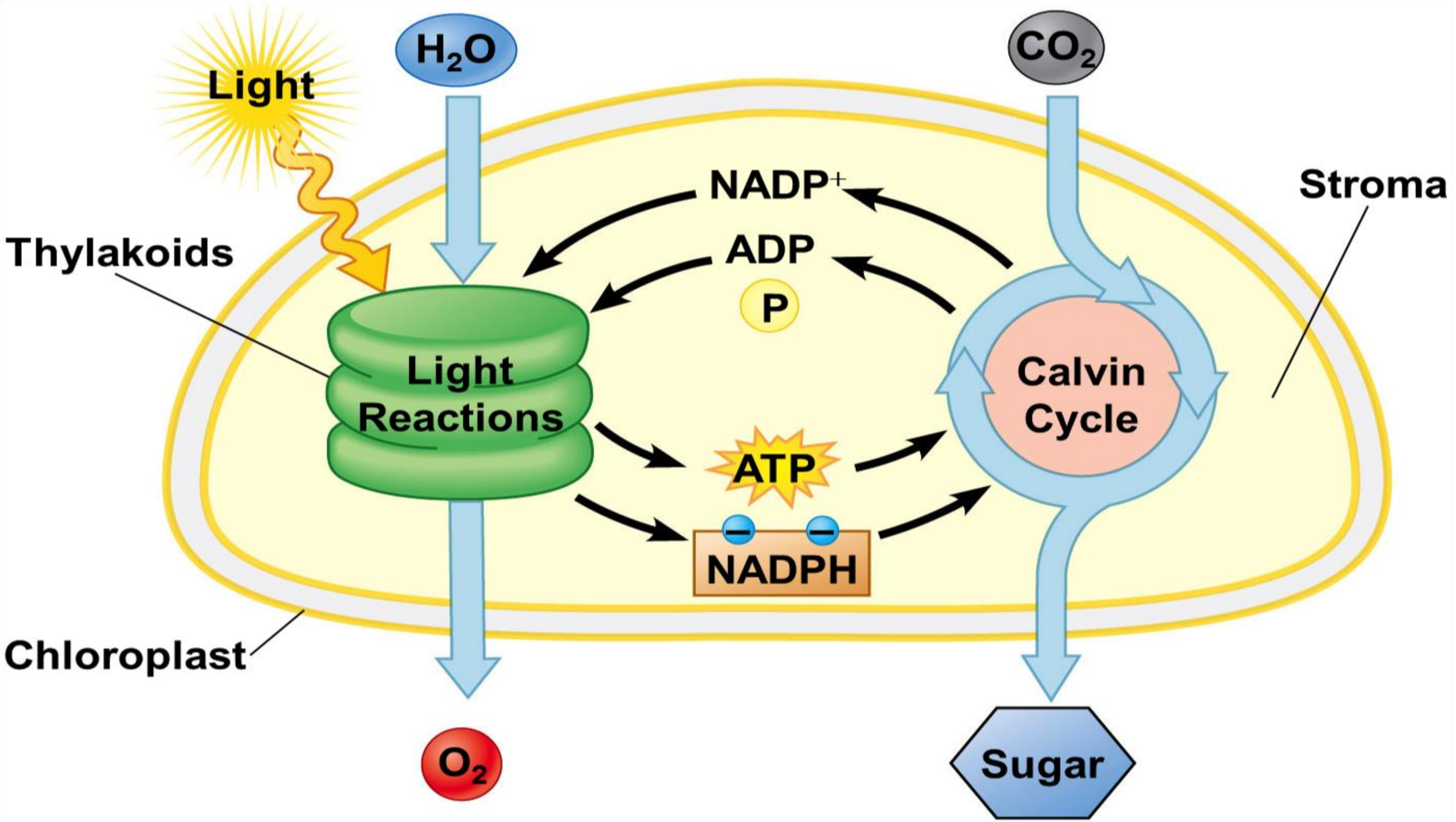
- Two PGAL molecules are bonded together to form glucose



Dark Reactions / Calvin Cycle / C_3

- The remaining carbon atoms and ATP regenerate RuBP
  - It's a cycle!

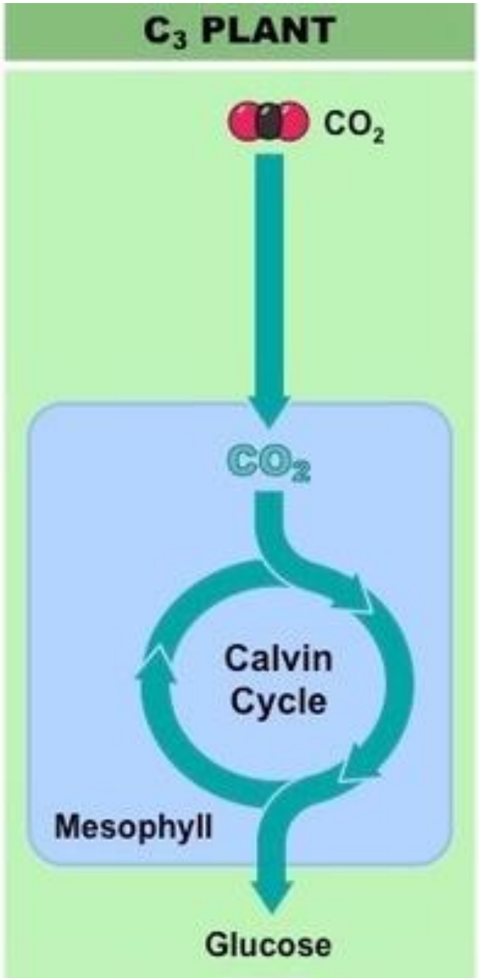



Light
H_2O
CO_2
Stroma
$NADP^+$
ADP
P
Thylakoids
Light Reactions
Calvin Cycle
ATP
NADPH
Chloroplast
O_2
Sugar

Dark Reactions / Calvin Cycle / C_3

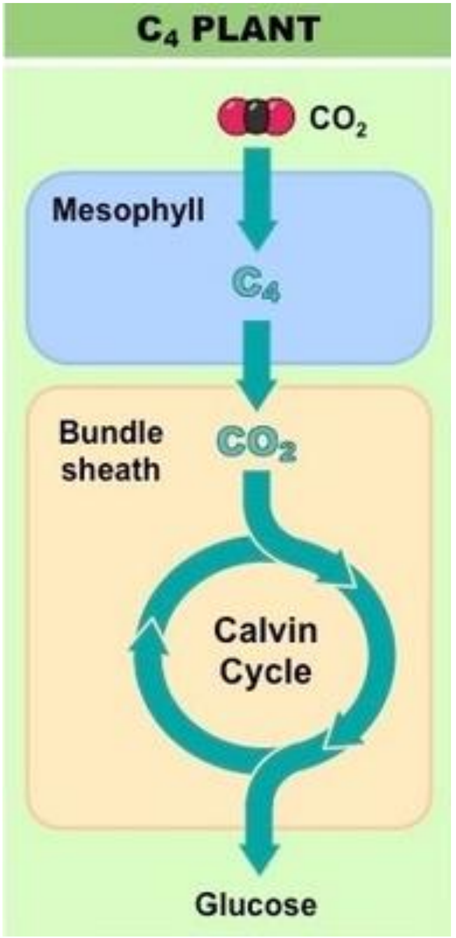
- There are two more methods of carbon fixation.
  - The C4 pathway
  - CAM
- Both will be explained during the class discussion.

Photosynthesis Pathways



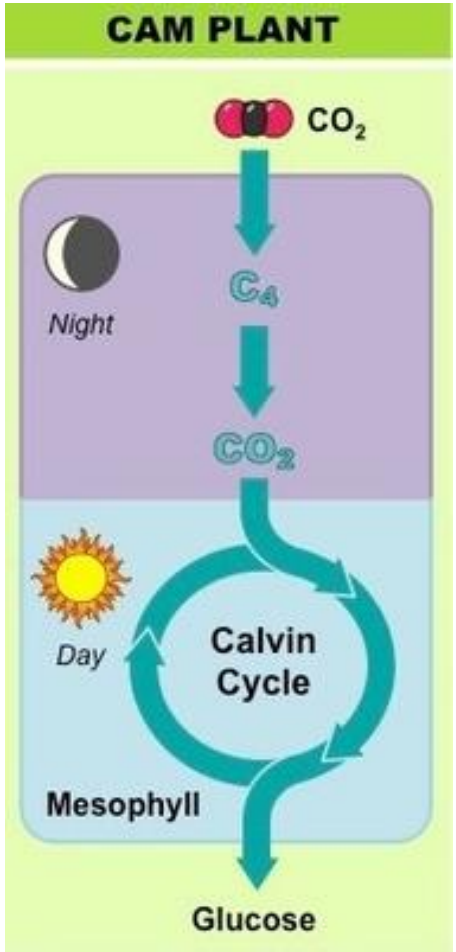
Type	Separation of initial CO_2 fixation and Calvin cycle	Stomata open	Best adapted to
C_3	No separation	Day	Cool, wet environments
C_4	Between mesophyll and bundle-sheath cells (in space)	Day	Hot, sunny environments
CAM	Between night and day (in time)	Night	Very hot, dry environments

C_4 Pathway



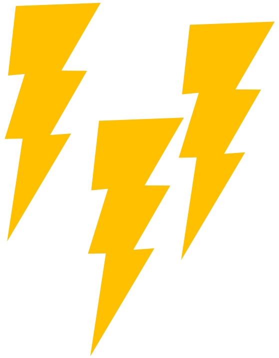
C4 PLANT
CO2
Mesophyll
C4
Bundle sheath
CO2
Calvin Cycle
Glucose

CAM Pathway


CAM PLANT
CO_2
Night
C_4
CO_2
Day
Calvin Cycle
Mesophyll
Glucose

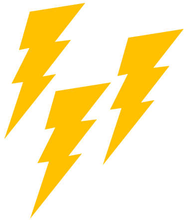
What do we mean by the Yin and Yang of life?

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

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

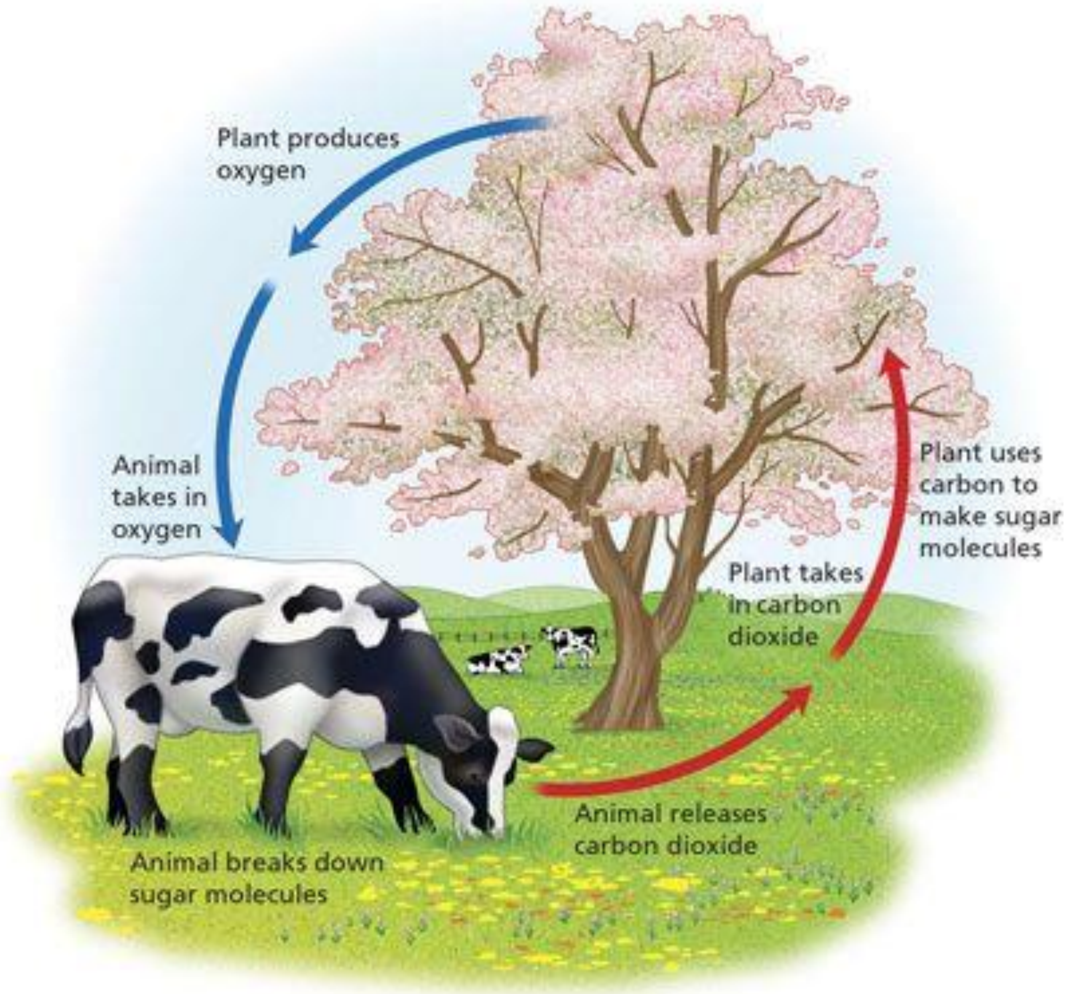
What do we mean by the Yin and Yang of life?

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

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

The Ying and Yang of Life

- Without respiration photosynthesis cannot exist
- Without photosynthesis, respiration cannot exist



Go Farther Grasshopper!

- Now the question to see if you understand:
  - Which came first?
    - Respiration
    - Photosynthesis

Snatch the Pebble From My Hand!

- What do you think is the order that these processes developed on Earth
  - Photosynthesis
  - Anaerobic respiration
  - Aerobic respiration
- Why?