General Biology 1
BIO1101
Syllabus & Textbook: http://goo.gl/rvgdrH

Letter Grade	Numerical Ranges
A	93-100
A-	90-92.9
B+	87-89.9
B	83-86.9
B-	80-82.9
C+	77-79.9
C	70-76.9
D	60-69.9
F	59.9 and below

Lecturer: Michael Gotesman, PhD
Email: mgotesman@citytech.cuny.edu

OER
Lecture:https://openlab.citytech.cuny.edu/bio-oer/page/2/
Lab: https://openlab.citytech.cuny.edu/bio-oer/

Grade Breakdown:
Exams (4): 20% Each
Quizzes: 20% Average

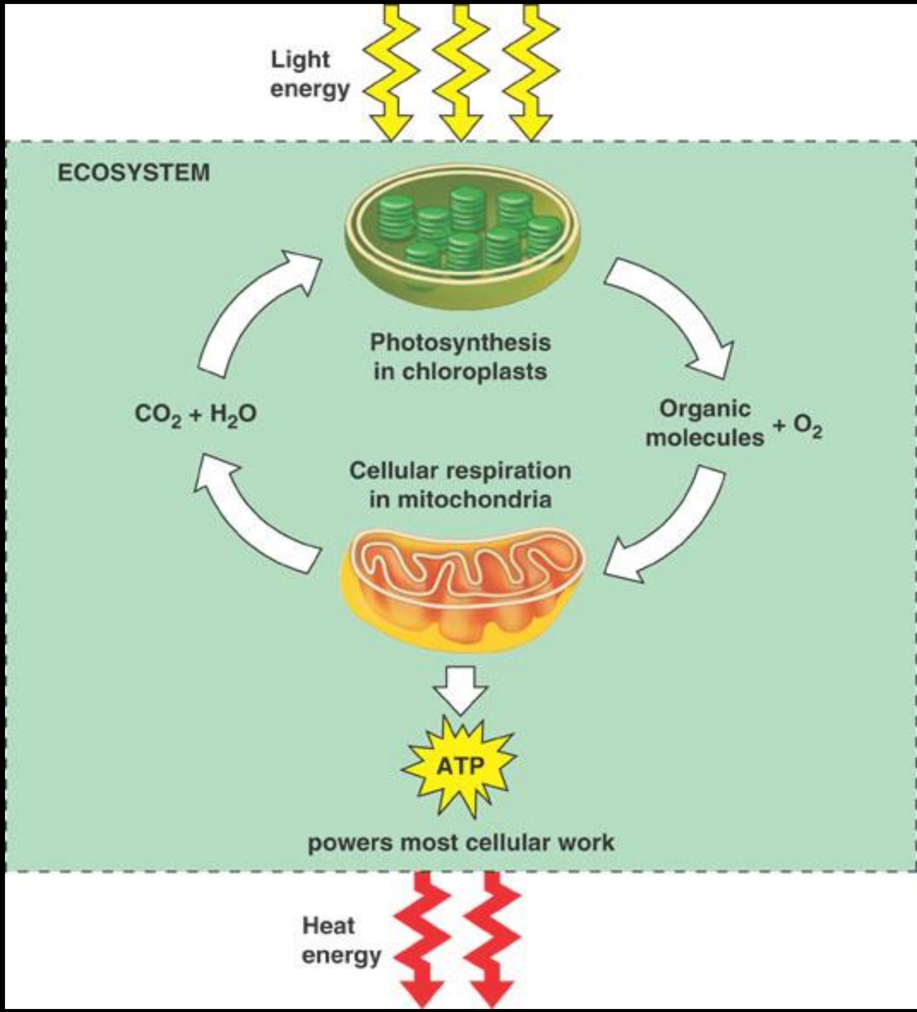
Bio 1101- Lecture 18-19

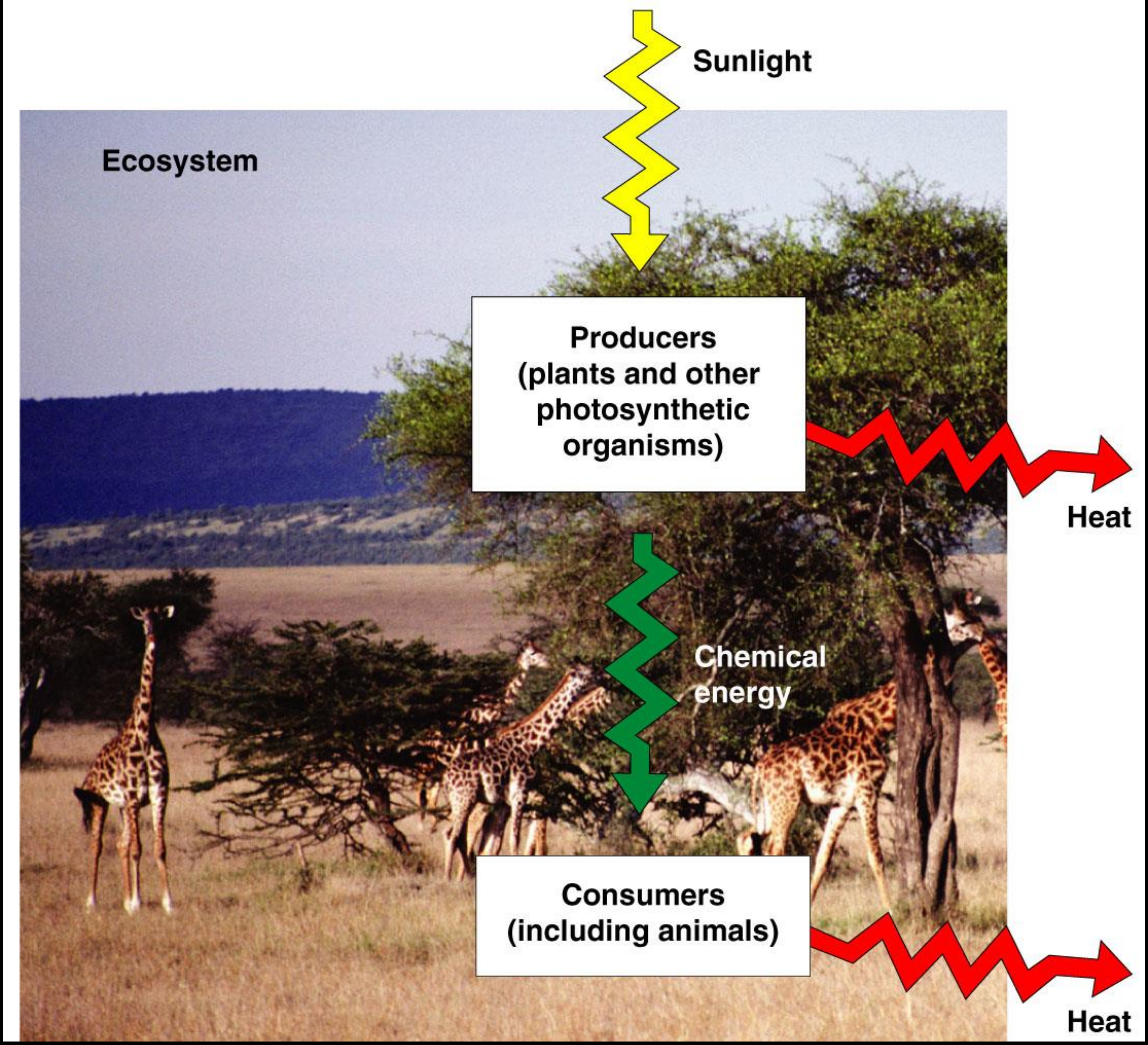
Fall 2017

Photosynthesis

Review of Energy Flow

- E comes to earth from the sun:
- Solar E converted to chemical E by photosynthesis (chloroplasts)
  - Glucose
- Cells harvest Chemical E by Respiration (mitochondria)
  - ATP
- The E of ATP powers cellular "work"
  - Most E is actually lost as heat along the way!




Sunlight
Ecosystem
Producers (plants and other photosynthetic organisms)
Heat
Chemical energy
Consumers (including animals)
Heat

Modes of Nutrition

Trough →

- **Heterotroph** – "other feeder" Acquires organic molecules from other organisms.
- **Autotroph** – "self feeder." Makes their own organic molecules -- (atrophy).
- **Photoautotroph** – employs photosynthesis to fix E from the sun into organic molecules (from CO_2 and H_2O)
  - These supply all the world with organic molecules and energy!

Photosynthetic Organisms

- All life on Earth depends on a star 93 million miles away (~**8 light**-minutes in distance)
- Provides photosynthesizers with solar energy

- **Photosynthesis**:
  - A process that captures solar energy
  - Transforms solar energy into chemical energy
  - Energy ends up stored in a carbohydrate

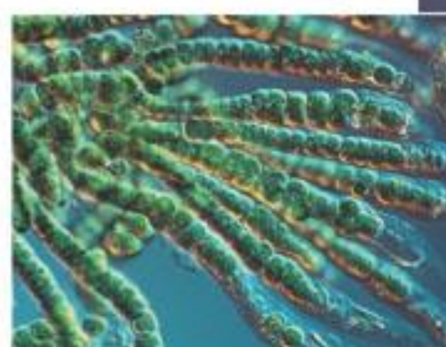
- **Photosynthesizers** produce all food energy
  - Only 42% of sun's energy directed towards Earth reaches surface
  - Of this, only 2% is captured by photosynthesizers
  - Of this, only a tiny portion results in biomass

(a) Plants

(b) Multicellular algae

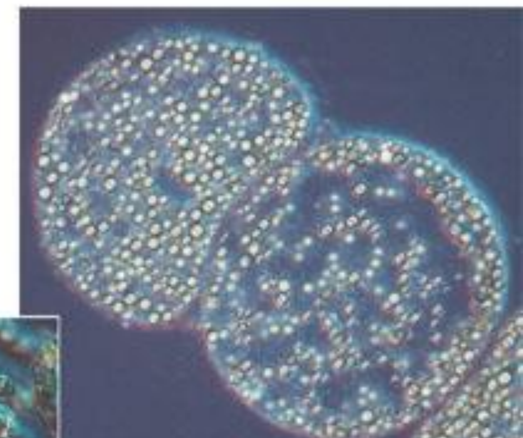
(c) Unicellular protist

10 µm



(d) Cyanobacteria

40 µm



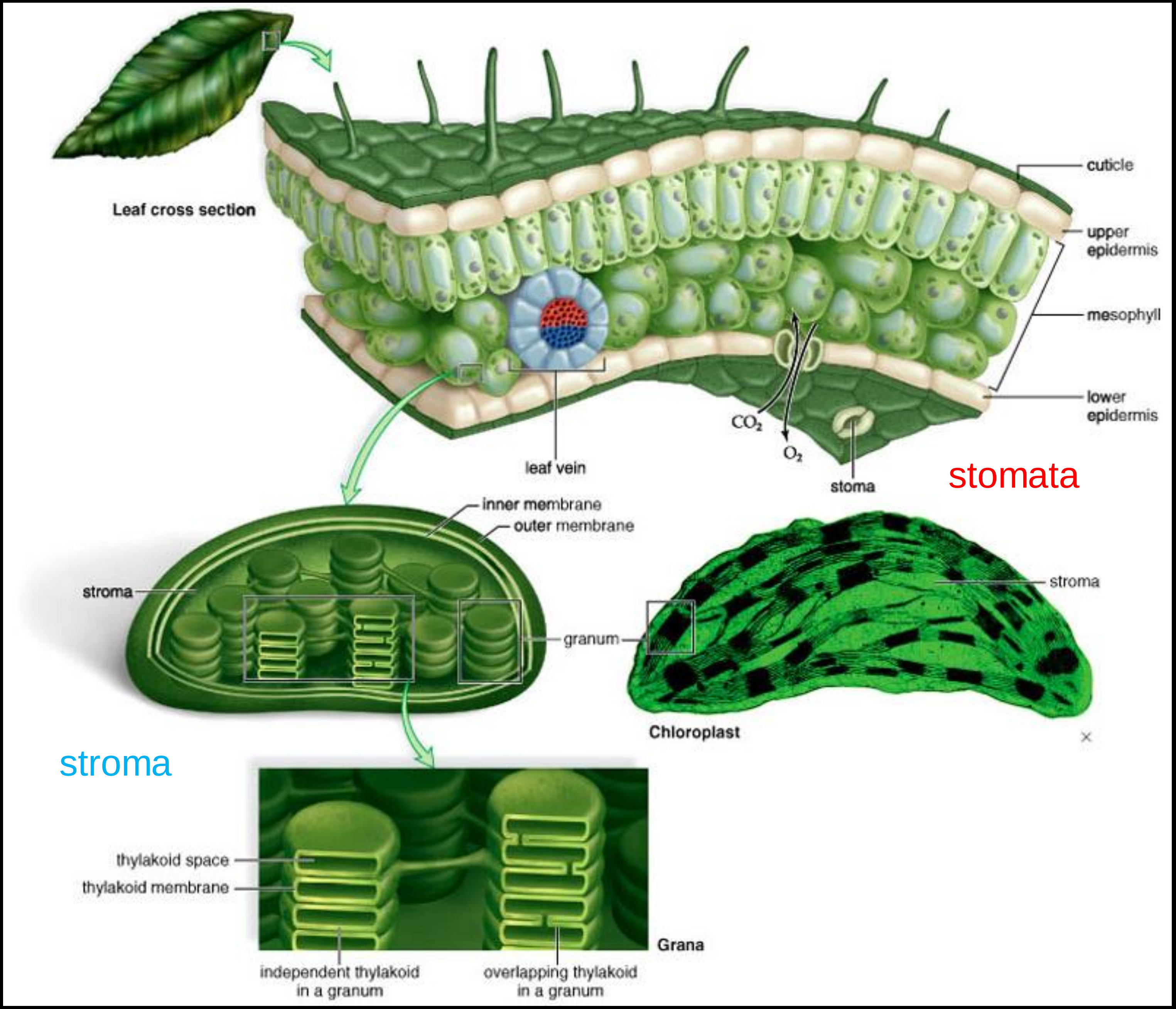
(e) Purple sulfur bacteria

1.5 µm

Photosynthesis

- Photosynthesis takes place in the green portions of plants
  - Leaf of flowering plant contains mesophyll tissue
  - Cells containing chloroplasts
  - Specialized to carry on photosynthesis
- CO_2 enters leaf through stoma/stomata
  - Diffuses into chloroplasts in mesophyll cells
  - In stroma, CO_2 combined with H_2O to form $C_6H_{12}O_6$ (sugar)
  - Energy supplied by light

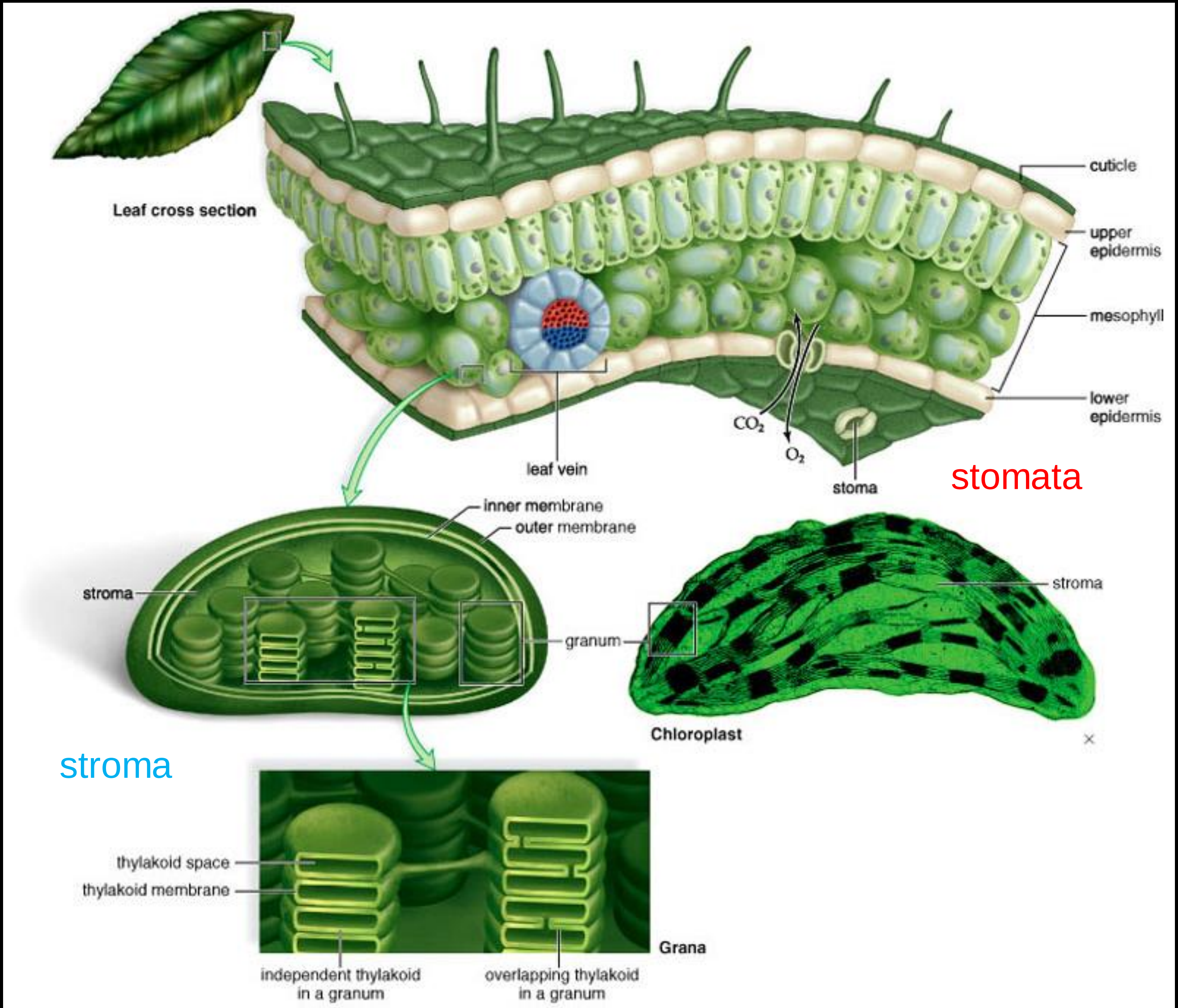
Leaves and Photosynthesis



Chloroplasts – site of photosynthesis

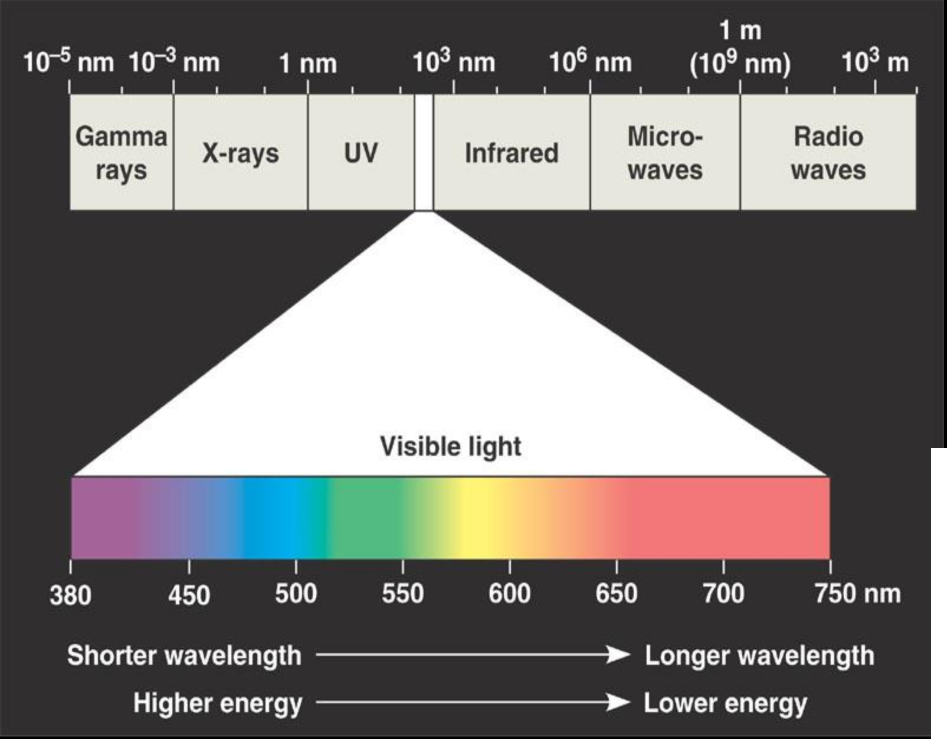
- Green parts of plants have chloroplasts (leaves are main site)
  - **Mesophyll** – tissue layer inside a leaf with high concentration of chloroplasts
  - **Chlorophyll** – green pigment that absorbs light
- **Stomata** – pores in the leaf where CO_2 enters and O_2 exits
- **Veins** – bring H_2O to the leaf from roots
- **Stroma** – central interior of chloroplasts (inside both membranes)
- **Thylakoids** – membrane sacs inside stroma that contain chlorophyll

Leaves and Photosynthesis

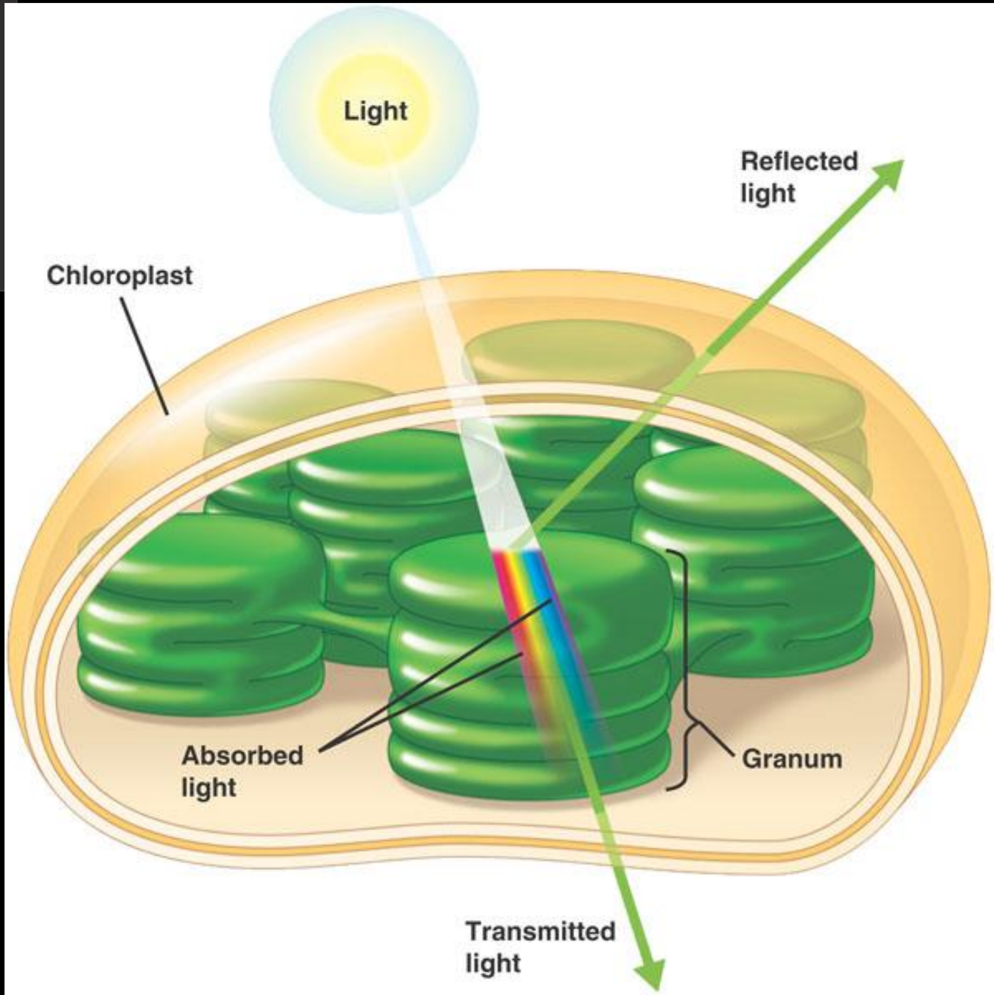


Photosynthetic Pigments

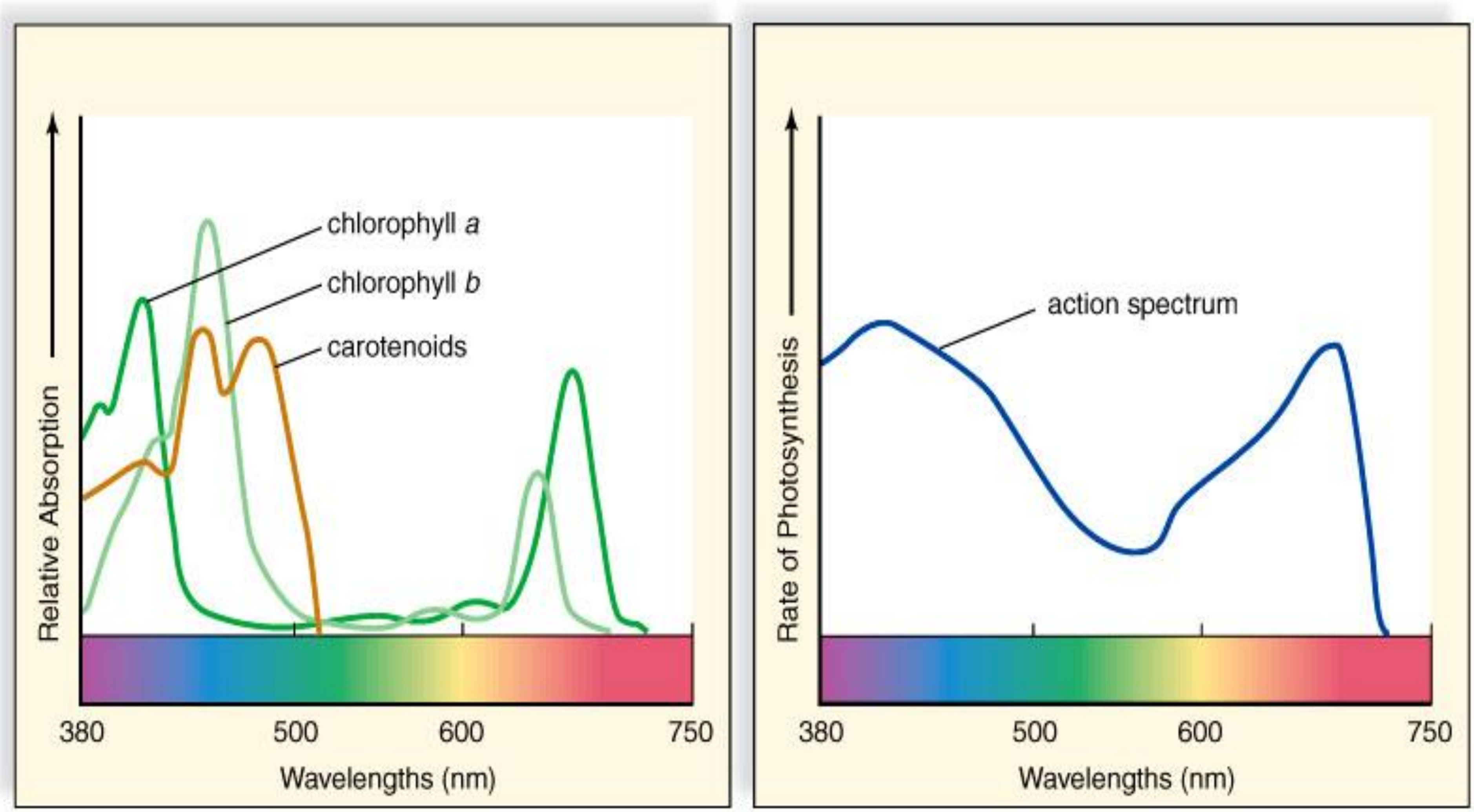
- Pigments:
  - Chemicals that absorb some colors in rainbow more than others
  - Colors least absorbed reflected/transmitted most
- Absorption Spectra
    - Graph showing relative absorption of the various colors of the rainbow
    - Chlorophyll is green because it absorbs much of the reds and blues of white light



Shorter Wavelength → More energy,
Longer Wavelength → Less Energy
Chlorophyll is green because it absorbs much of the reds and blues of white light



Photosynthetic Pigments



a. The absorption spectrums for chlorophylls *a* and *b* and the carotenoids.

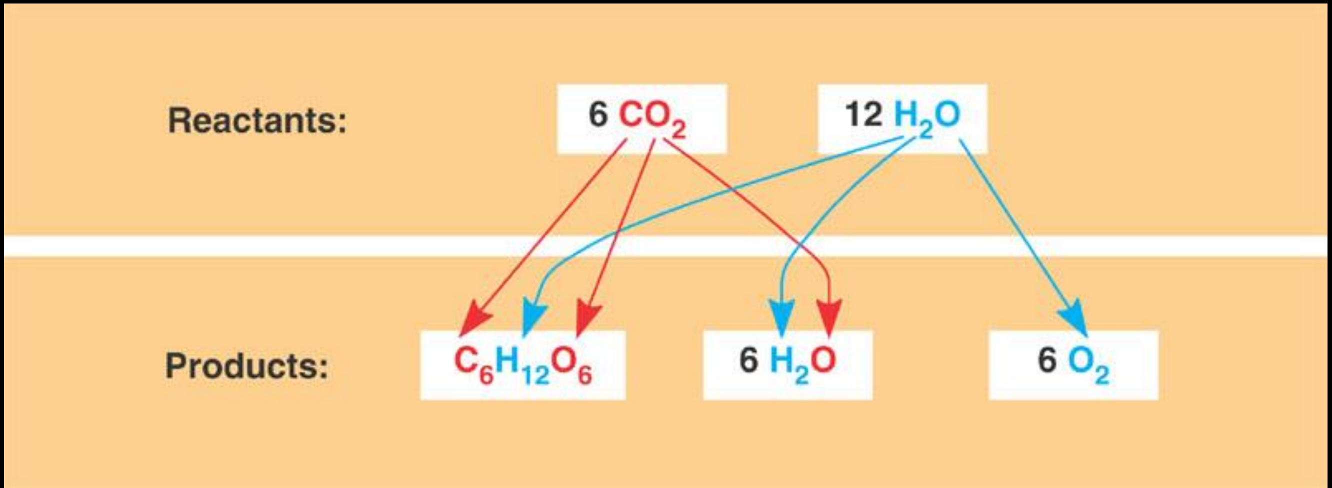
b. The action spectrum for photosynthesis.

Overview of Photosynthesis

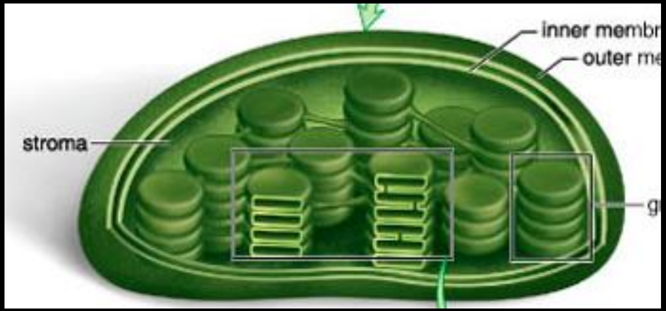
- It is the exact reverse of Respiration

  <u>***Solar energy +***</u> $6\ CO_2 + 6\ H_2O$ □ $C_6H_{12}O_6 + O_2$

  – $\Delta G = +686$ kcal/mol
  – ENDERGONIC, so E is required
- It is also a series of redox reactions, except:
  – Carbon is REDUCED
  – Water is SPLIT (oxidized) to oxygen and electrons (H^-)
- The E-'s are taken from H_2O (as H^-)
  – Begin as low-E
  – get "energized" by sunlight, becoming high-energy
  – Eventually passed to CO_2 (as H^-) to form glucose

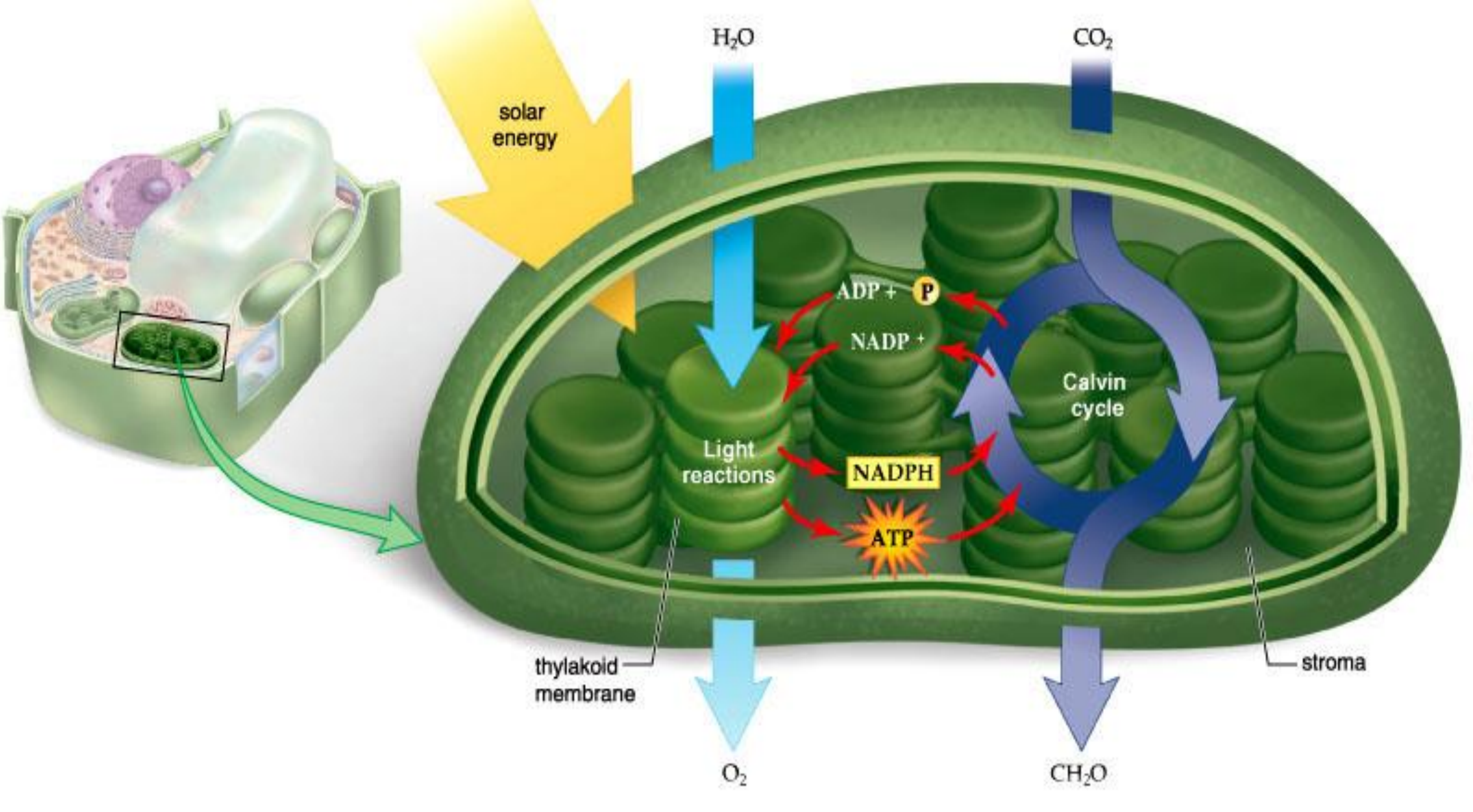


Two phases of Photosynthesis

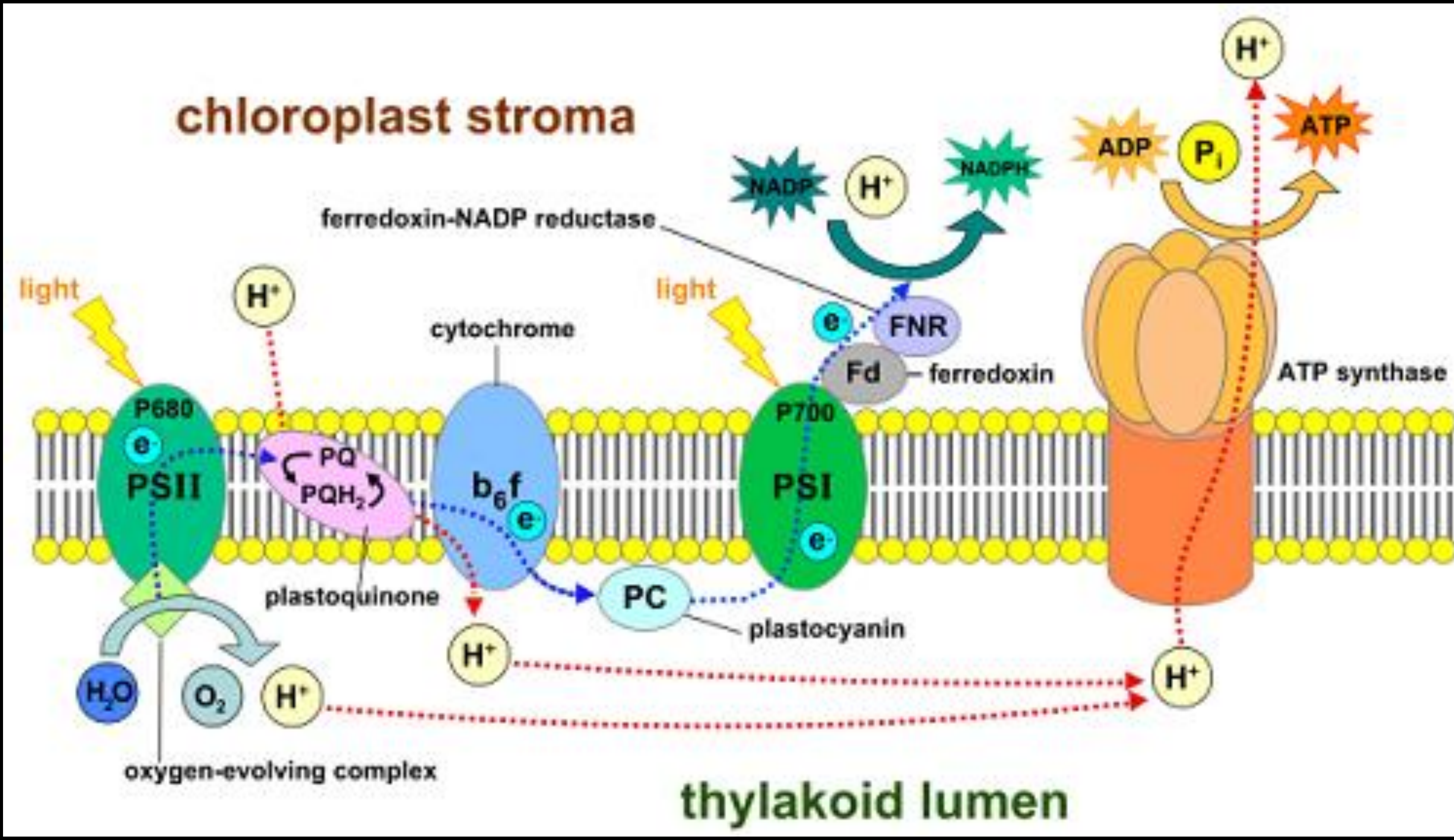


- **Light Reactions**
  - Occur in Thylakoid Membranes
  - Chlorophyll aborbs solar energy
  - Low-E e^-'s from H_2O are "excited" and passed to $NADP^+$ to form NADPH
  - Some ATP is formed (electron transport chain, pumping of H+). This is called **Photo-phosphorylation**
  - O_2 is released
- **Calvin Cycle** (aka "dark reactions")
  - Occurs in the Stroma
  - **Carbon Fixation** – CO_2 is reduced to a carbohydrate
  - Carbon is reduced by addition of the high-E e-'s from NADPH
  - This costs some ATP.

Photosynthesis Overview



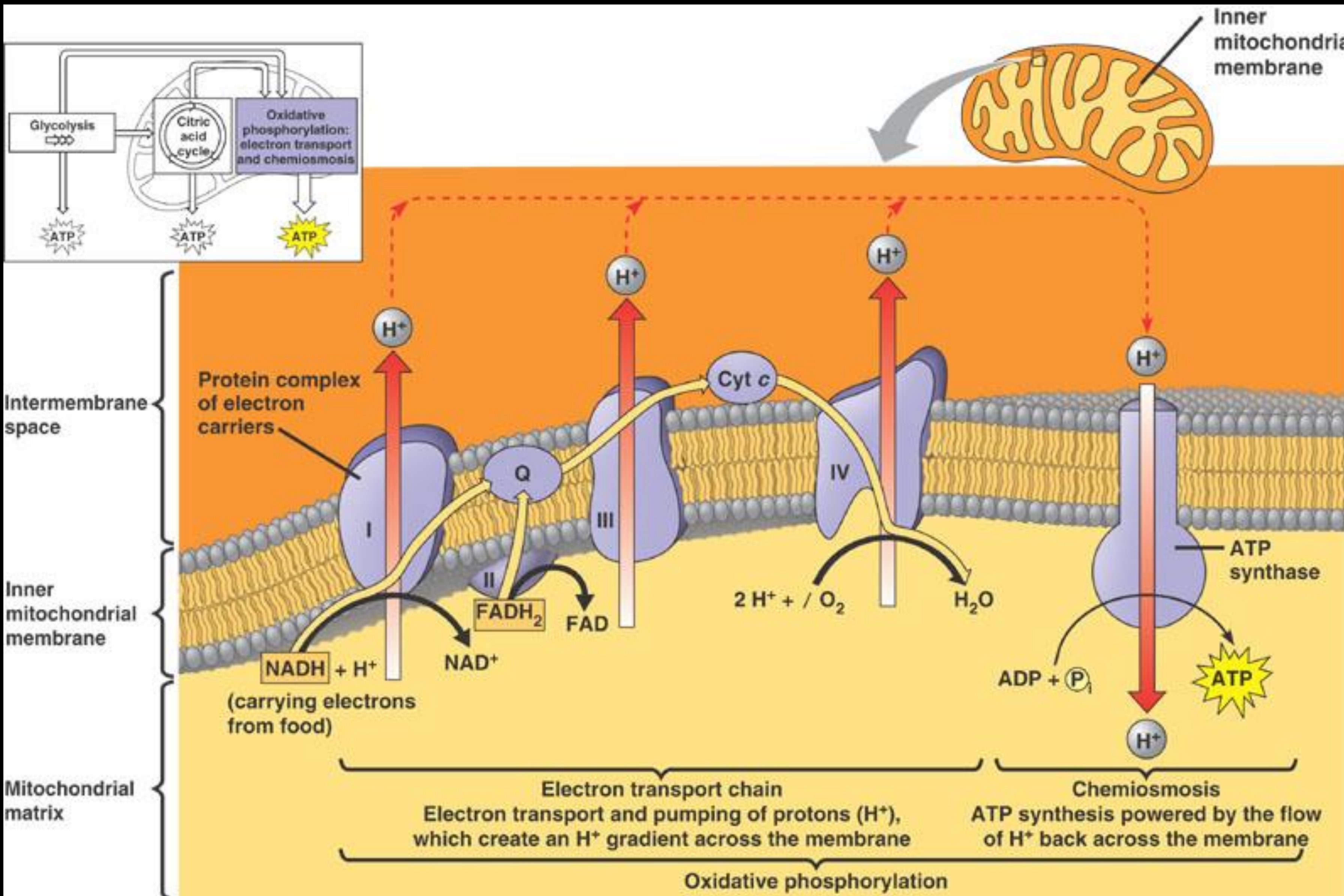
Light Reactions

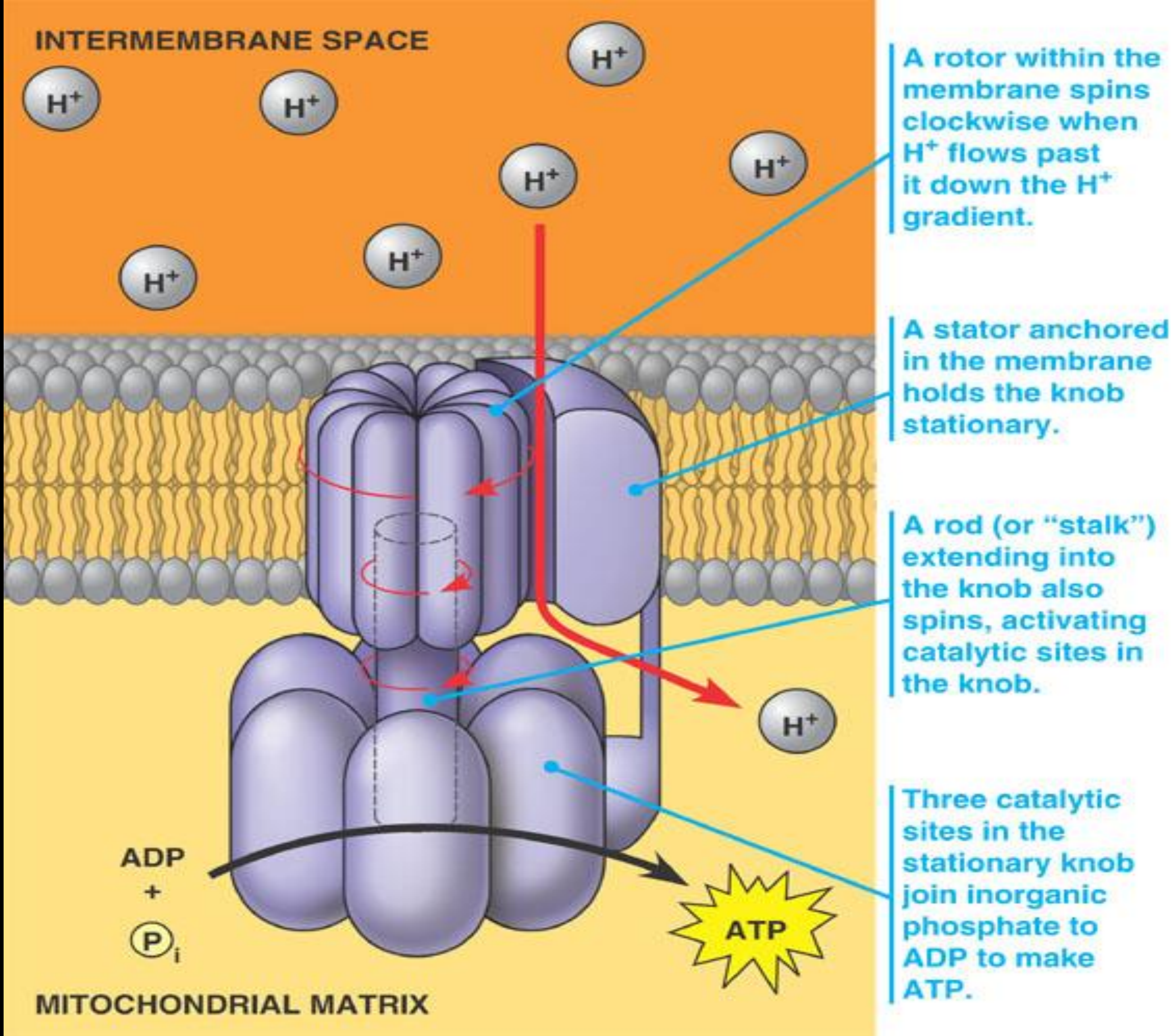


What Does This Look Like?

What gives the e⁻'s to the ETC?

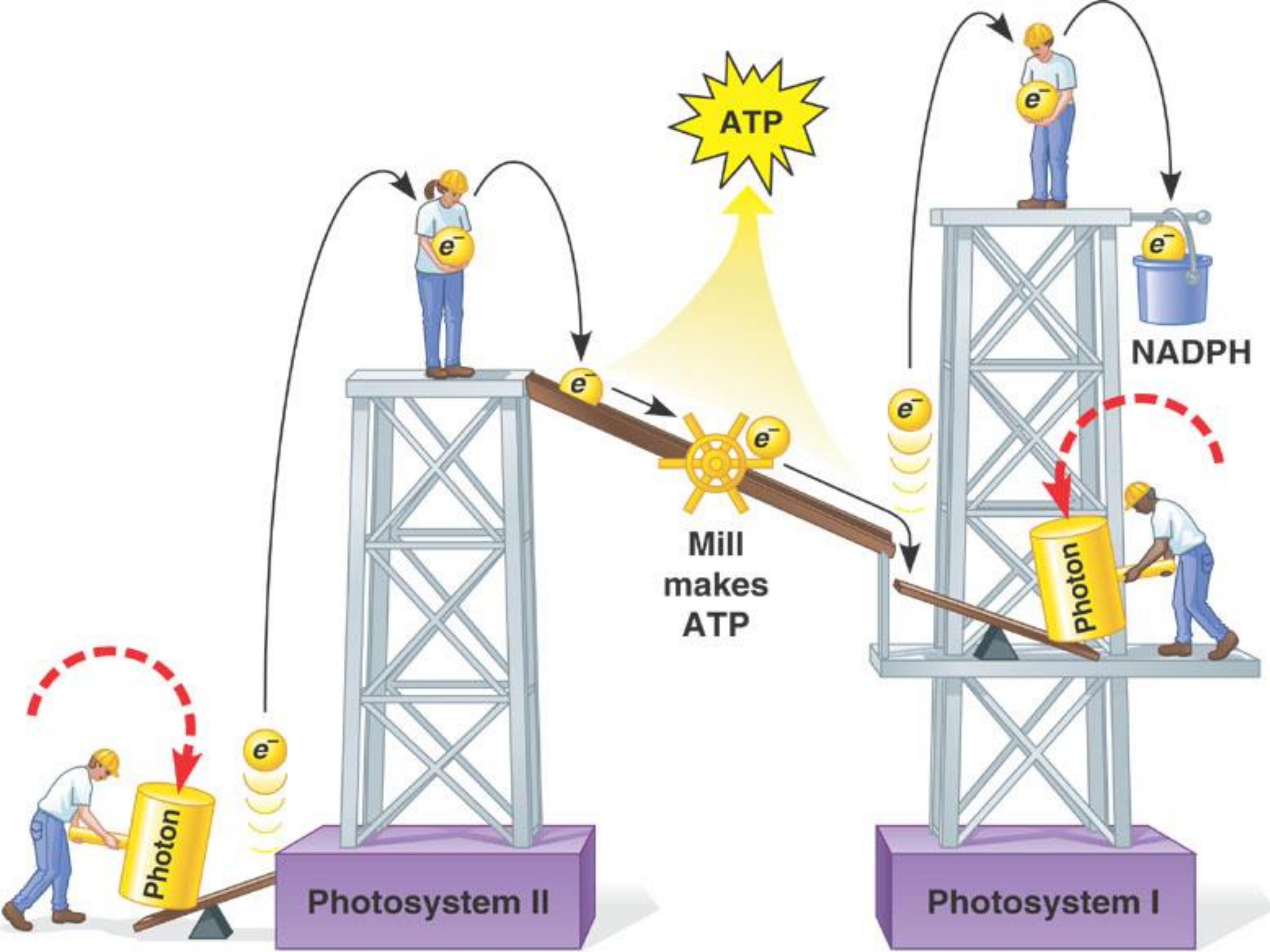
What does the ETC pump and where?




INTERMEMBRANE SPACE
H+
A rotor within the membrane spins clockwise when H+ flows past it down the H+ gradient.
A stator anchored in the membrane holds the knob stationary.
A rod (or "stalk") extending into the knob also spins, activating catalytic sites in the knob.
Three catalytic sites in the stationary knob join inorganic phosphate to ADP to make ATP.
ADP
+
P i
ATP
MITOCHONDRIAL MATRIX

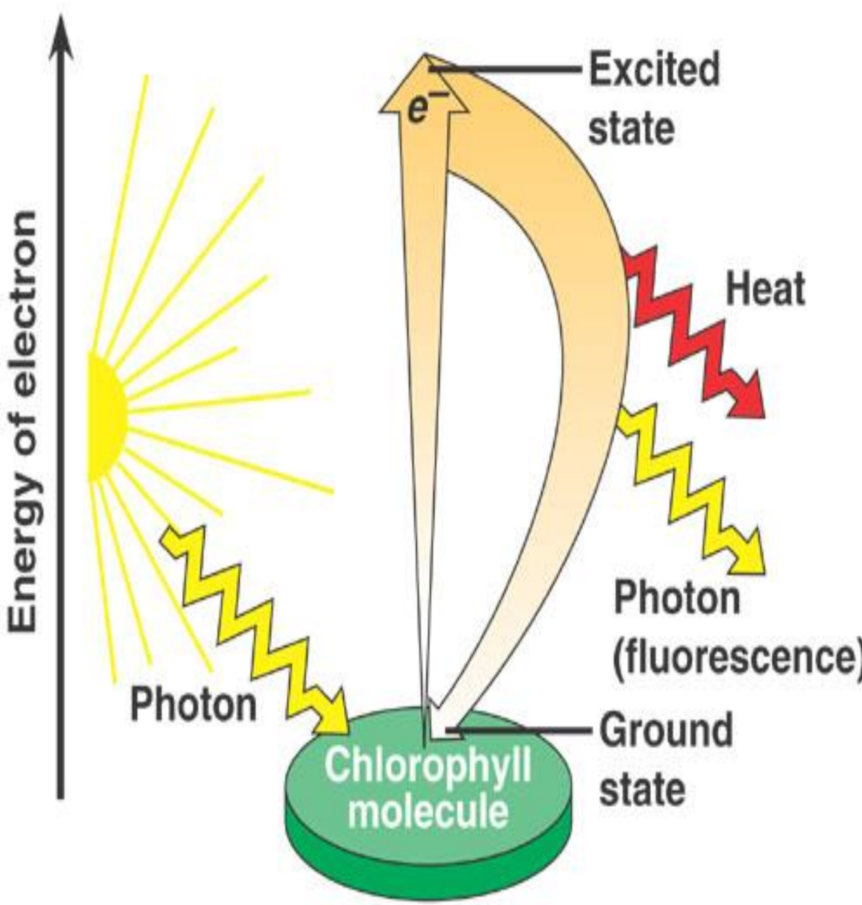
Photosynthetic Reactions: The Light Reactions

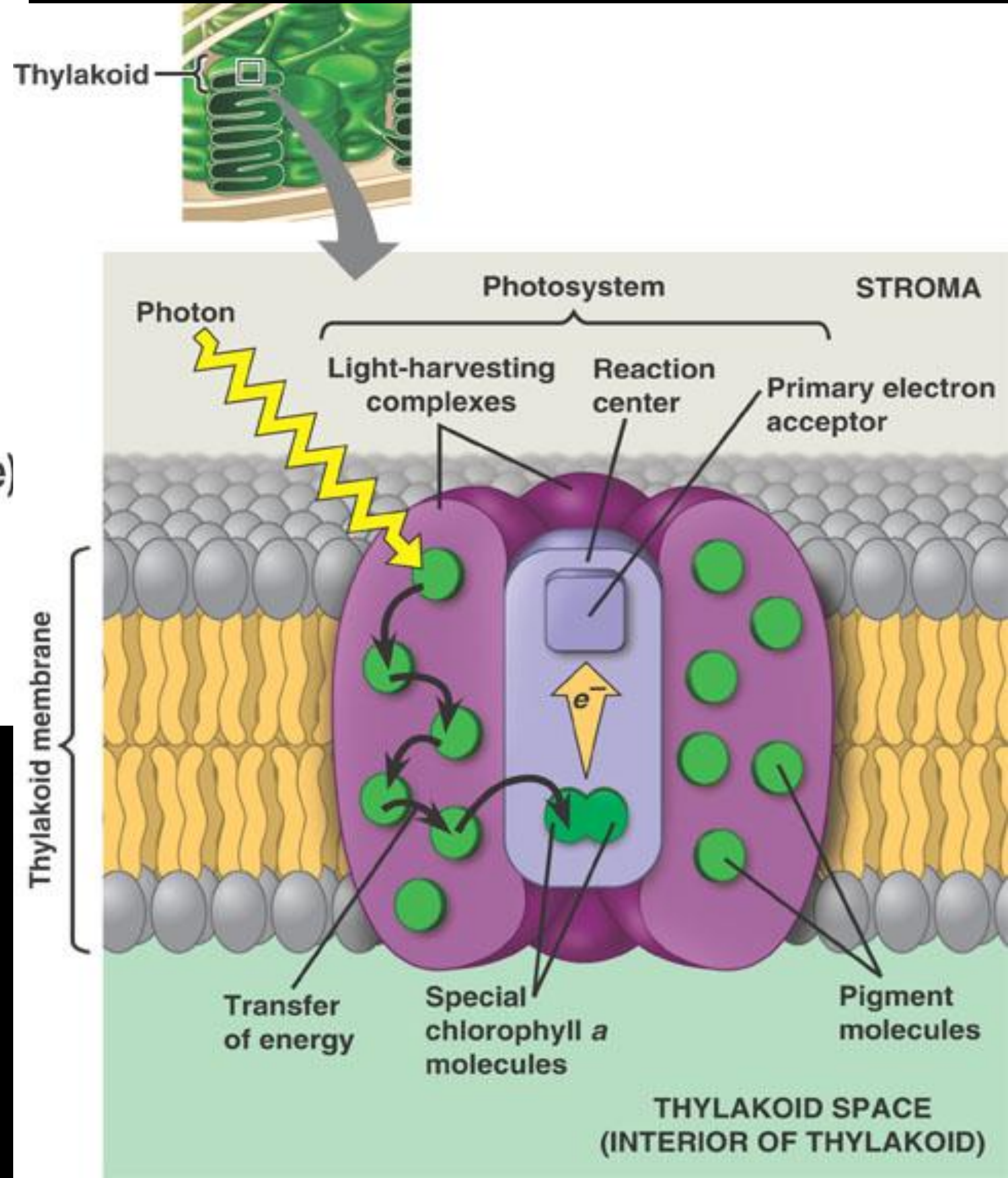
- Light reactions consist of two alternate electron pathways:
  - Noncyclic electron pathway
  - Cyclic electron pathway
- Capture light energy with photosystems
  - Pigment complex helps collect solar energy like an antenna
  - Occur in the thylakoid membranes
- Both pathways produce ATP
- The noncyclic pathway also produces NADPH

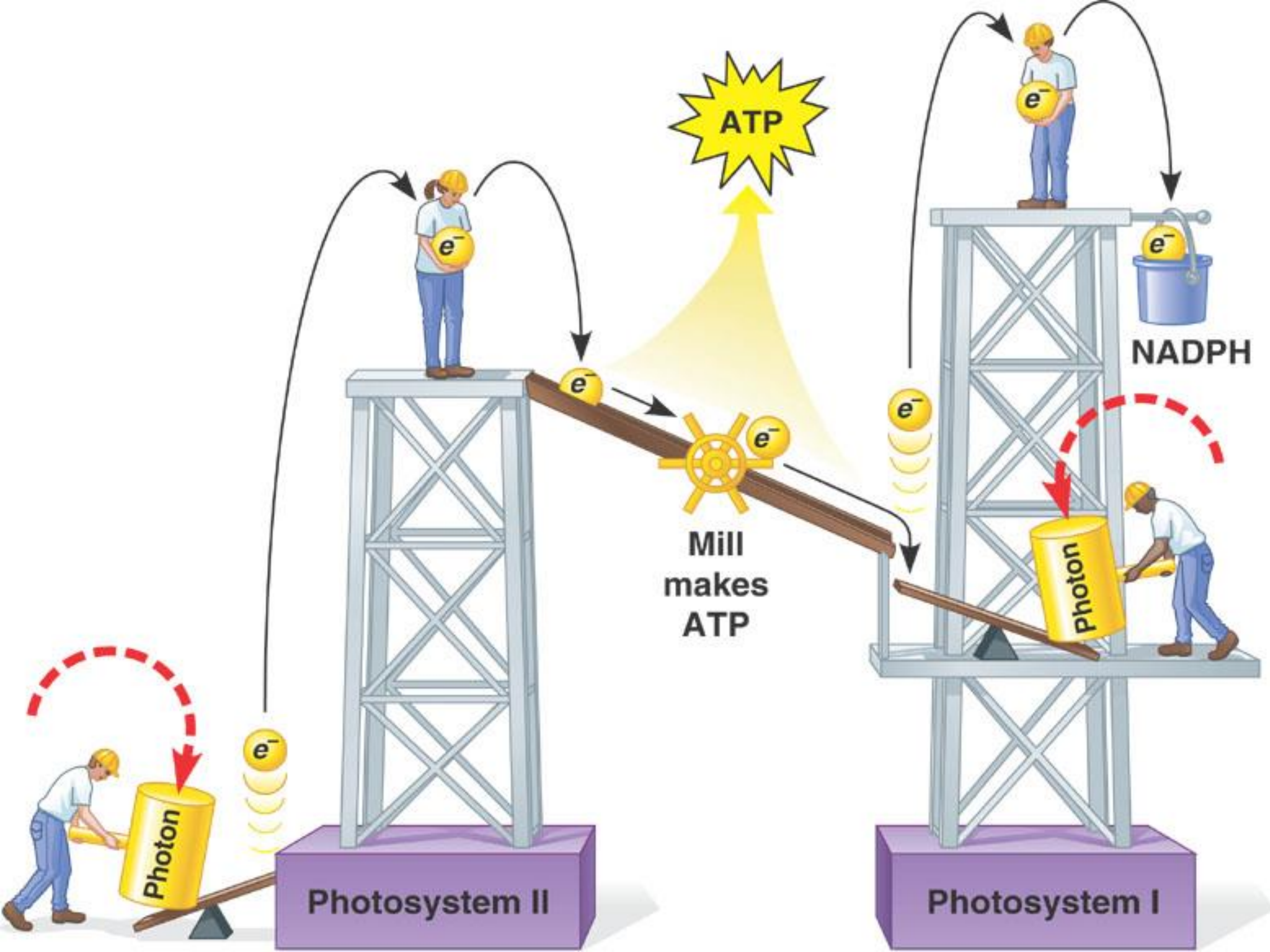

ATP
NADPH
Mill
makes
ATP
Photon
Photon
Photosystem II
Photosystem I
e⁻

Light Reactions: The Noncyclic Electron Pathway

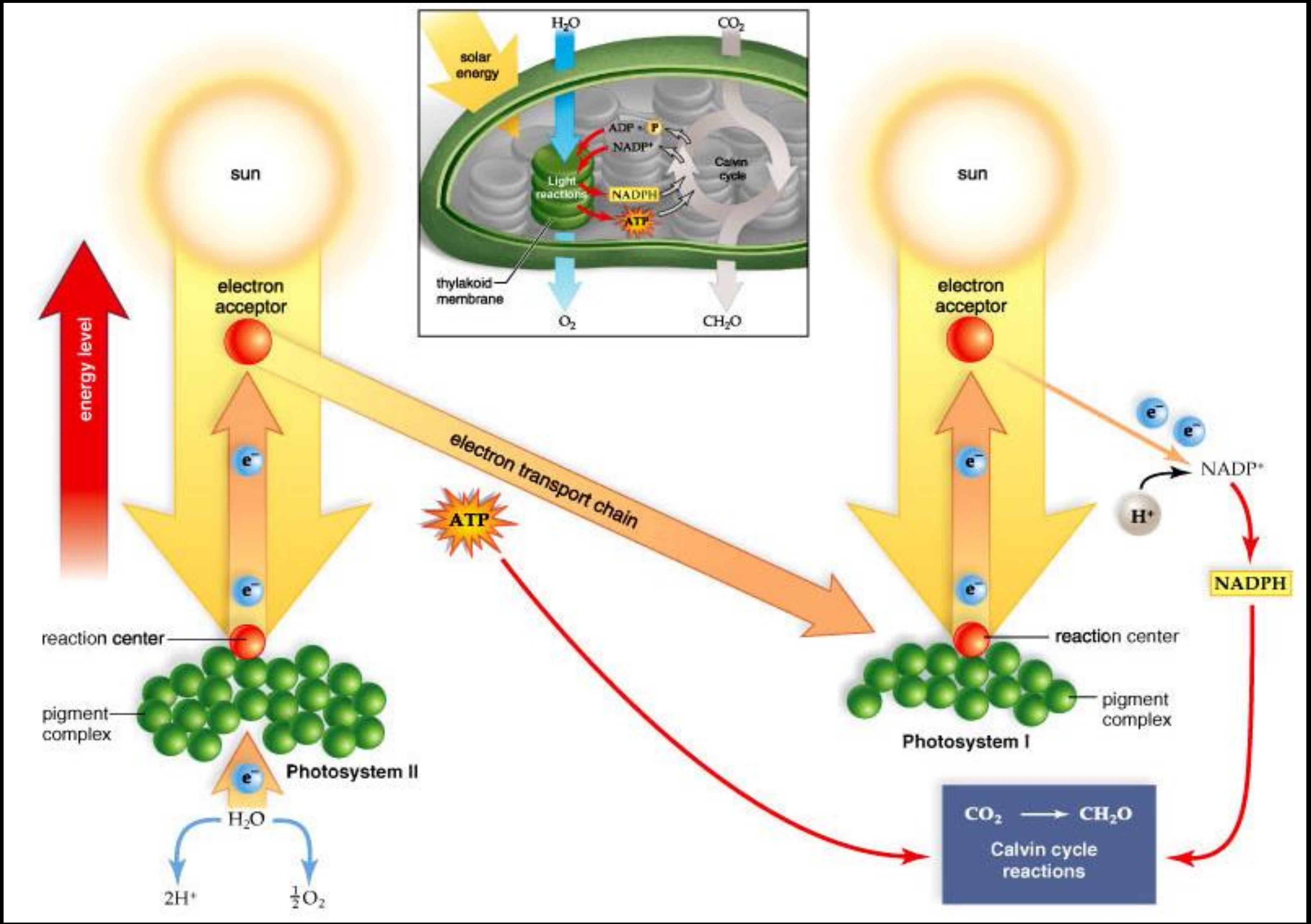
- Takes place in thylakoid membrane
- Uses two photosystems, PS-I and PS-II
- PS II captures light energy
- Causes an electron to be ejected from the reaction center (chlorophyll *a*)
  - Electron travels down electron transport chain to PS I
  - Replaced with an electron from water
  - Which causes H^+ to concentrate in thylakoid chambers => [H+] increases in thylakoid
  - Which causes ATP production
- PS I captures light energy and ejects an electron
  - Transferred *permanently* to a molecule of $NADP^+$
  - Causes NADPH production

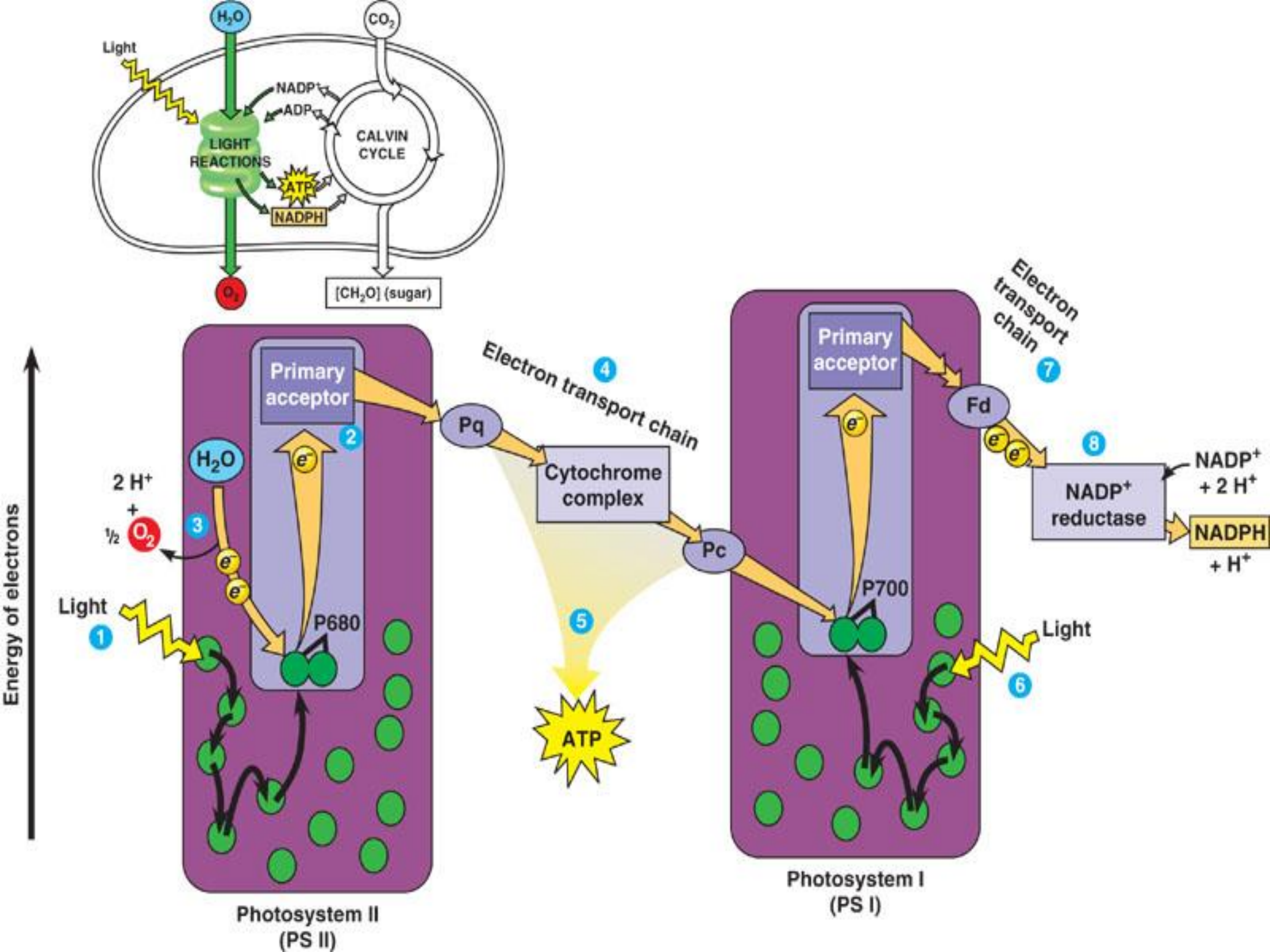

Energy of electron
Excited state
e^-
Heat
Photon
Photon (fluorescence)
Ground state
Chlorophyll molecule


Thylakoid
Photosystem
STROMA
Photon
Light-harvesting complexes
Reaction center
Primary electron acceptor
Thylakoid membrane
e^-
Transfer of energy
Special chlorophyll *a* molecules
Pigment molecules
THYLAKOID SPACE (INTERIOR OF THYLAKOID)


ATP
e⁻
e⁻
e⁻
e⁻
NADPH
e⁻
e⁻
Mill
makes
ATP
Photon
e⁻
Photon
Photosystem II
Photosystem I

Light Reactions: Noncyclic Electron Pathway



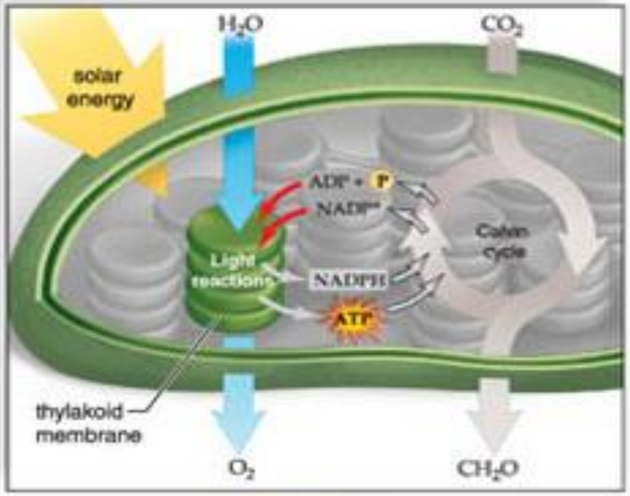


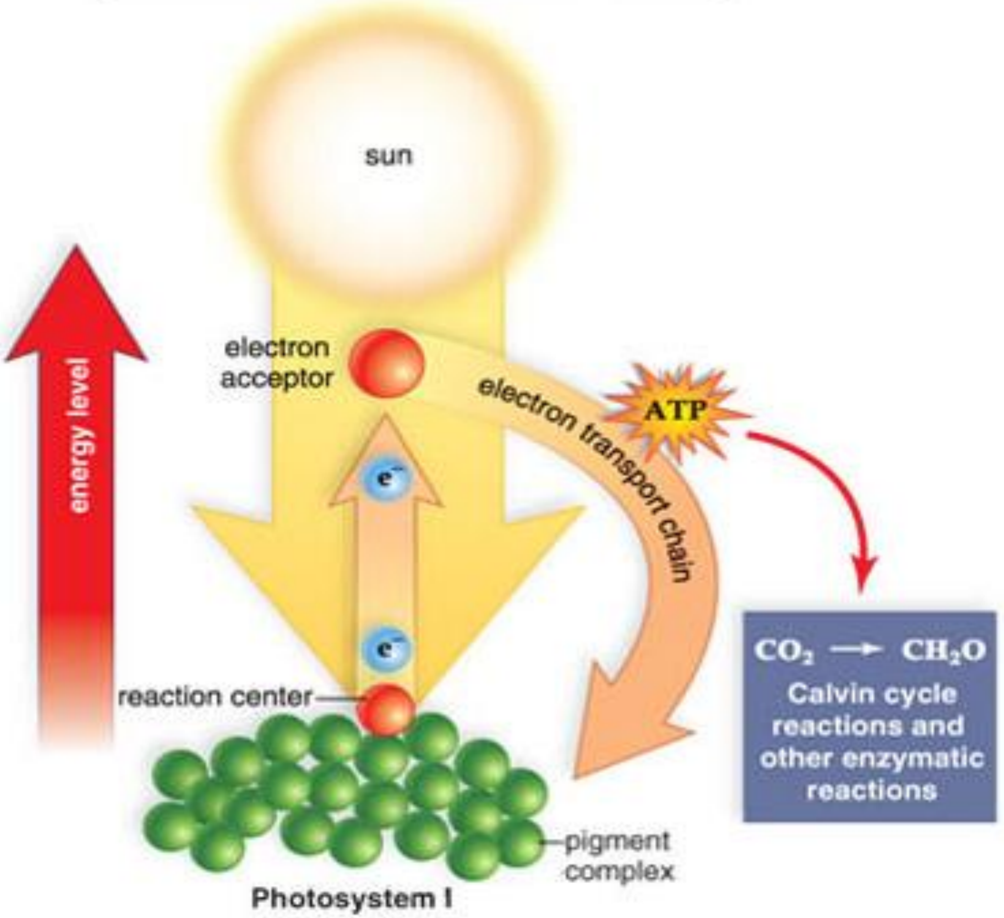
H2O
CO2
Light
NADP+
ADP
LIGHT REACTIONS
CALVIN CYCLE
ATP
NADPH
O2
[CH2O] (sugar)
Energy of electrons
Primary acceptor
Electron transport chain
Pq
Cytochrome complex
Pc
Primary acceptor
Electron transport chain
Fd
NADP+ reductase
NADP+ + 2 H+
NADPH + H+
H2O
2 H+ + ½ O2
e-
P680
P700
Light
ATP
Light
1
2
3
4
5
6
7
8
Photosystem II (PS II)
Photosystem I (PS I)

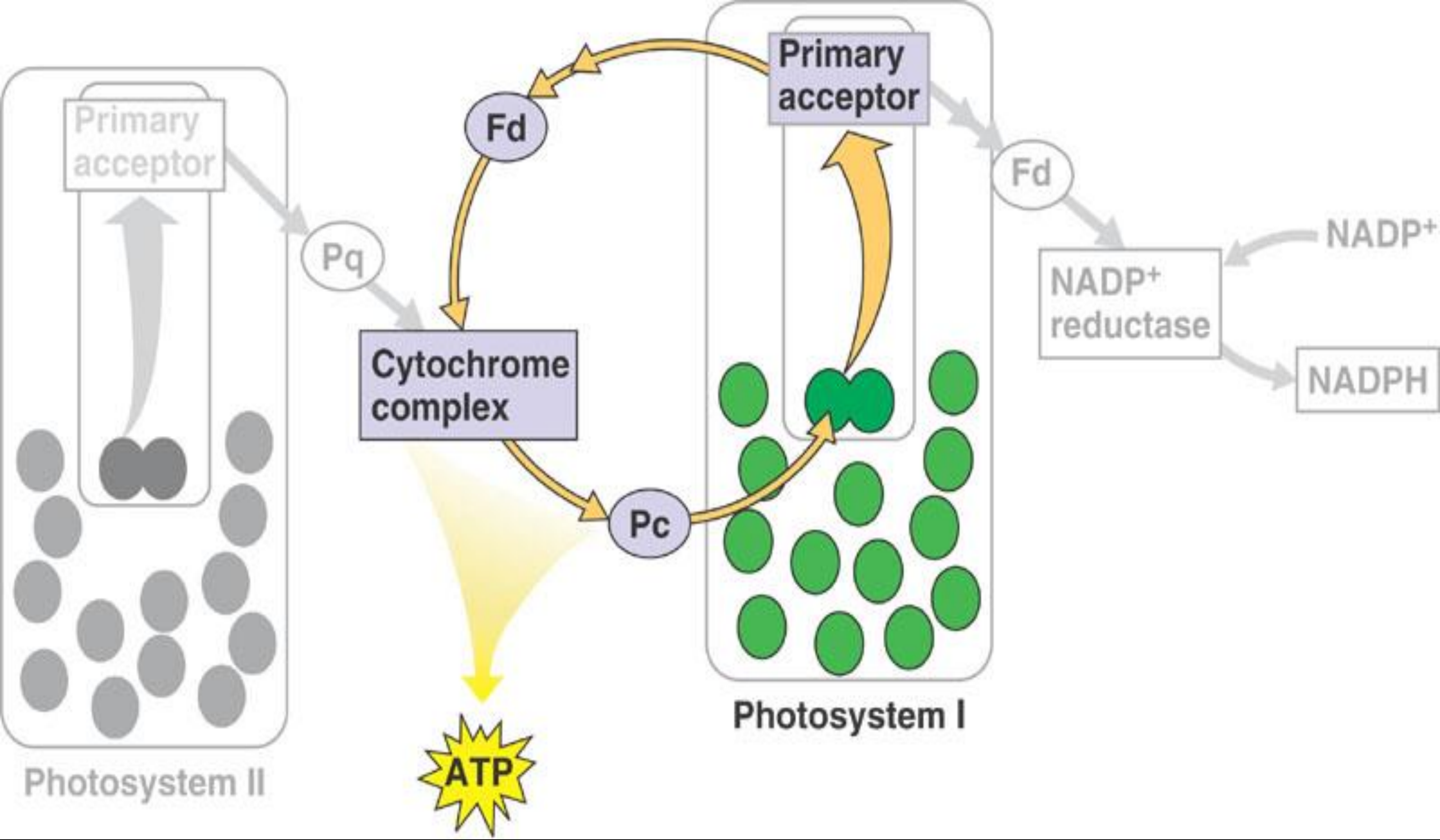
Light Reactions:
The Cyclic Electron Pathway

- Uses only photosystem I (PS-I)
- Begins when PS I complex absorbs solar energy
- Electron ejected from reaction center
  - Travels down electron transport chain
  - Causes H^+ to concentrate in thylakoid chambers
  - Which causes ATP production
  - Electron returns to PS-I (cyclic)
- Pathway only results in ATP production

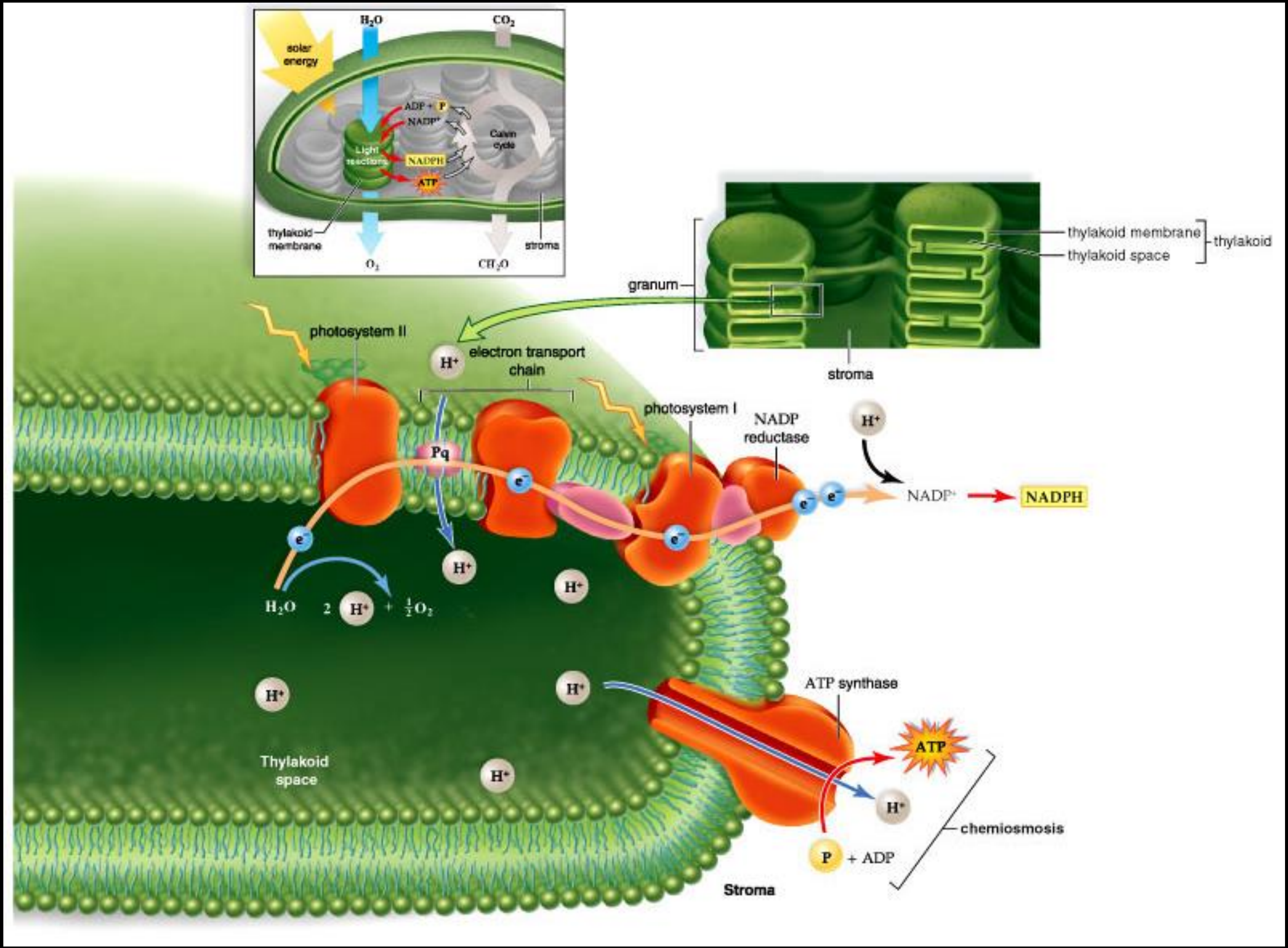
Light Reactions: Cyclic Electron Pathway






Primary acceptor
Pq
Photosystem II
Fd
Primary acceptor
Cytochrome complex
Pc
ATP
Photosystem I
Fd
NADP+
NADP+ reductase
NADPH

Organization of a Thylakoid



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Office Hours: Monday 11:30-12:30
Room: Pearl 304

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Lrnr: https://web.lrnr.us/login/auth

Grade Breakdown:

Exams (4): 20% Each
Quizzes: 20% Average

Important Dates:
Monday, April 30, 2018 Exam 3 (20% of total lecture grade)
Exam 3 will cover lectures 14-21 Bring Pencils

Recap

Chloroplasts – site of photosynthesis

Green parts of plants have chloroplasts (leaves are main site)

Mesophyll – tissue layer inside a leaf with high concentration of chloroplasts

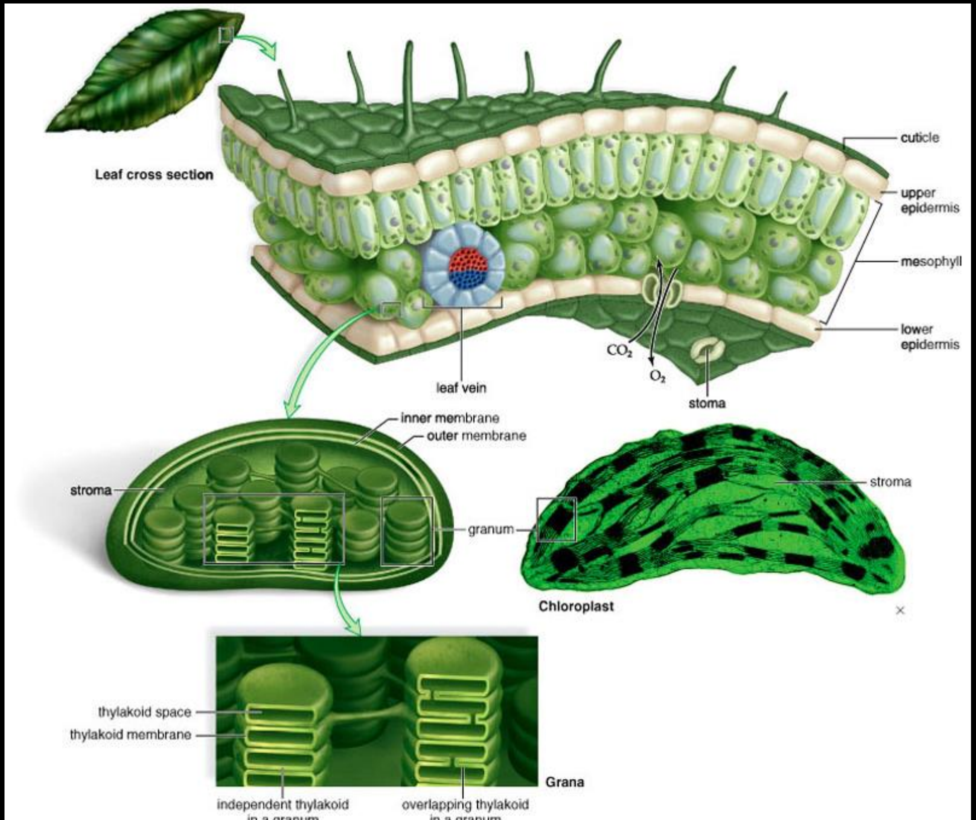
Chlorophyll – green pigment that absorbs light

Stomata – pores in the leaf where CO_2 enters and O_2 exits

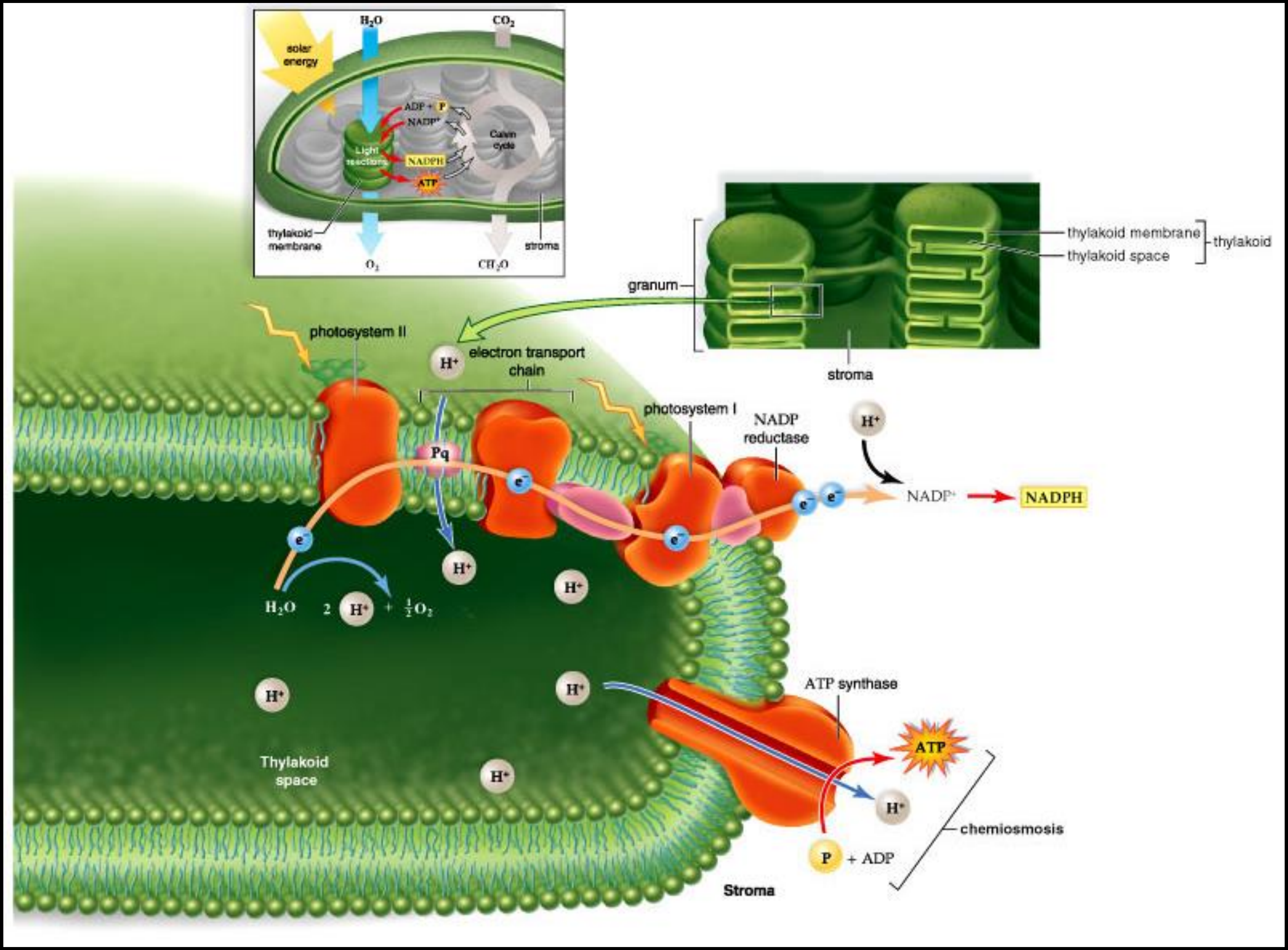
Stroma – central interior of chloroplasts (inside both membranes)

Thylakoids – membrane sacs inside stroma that contain chlorophyll

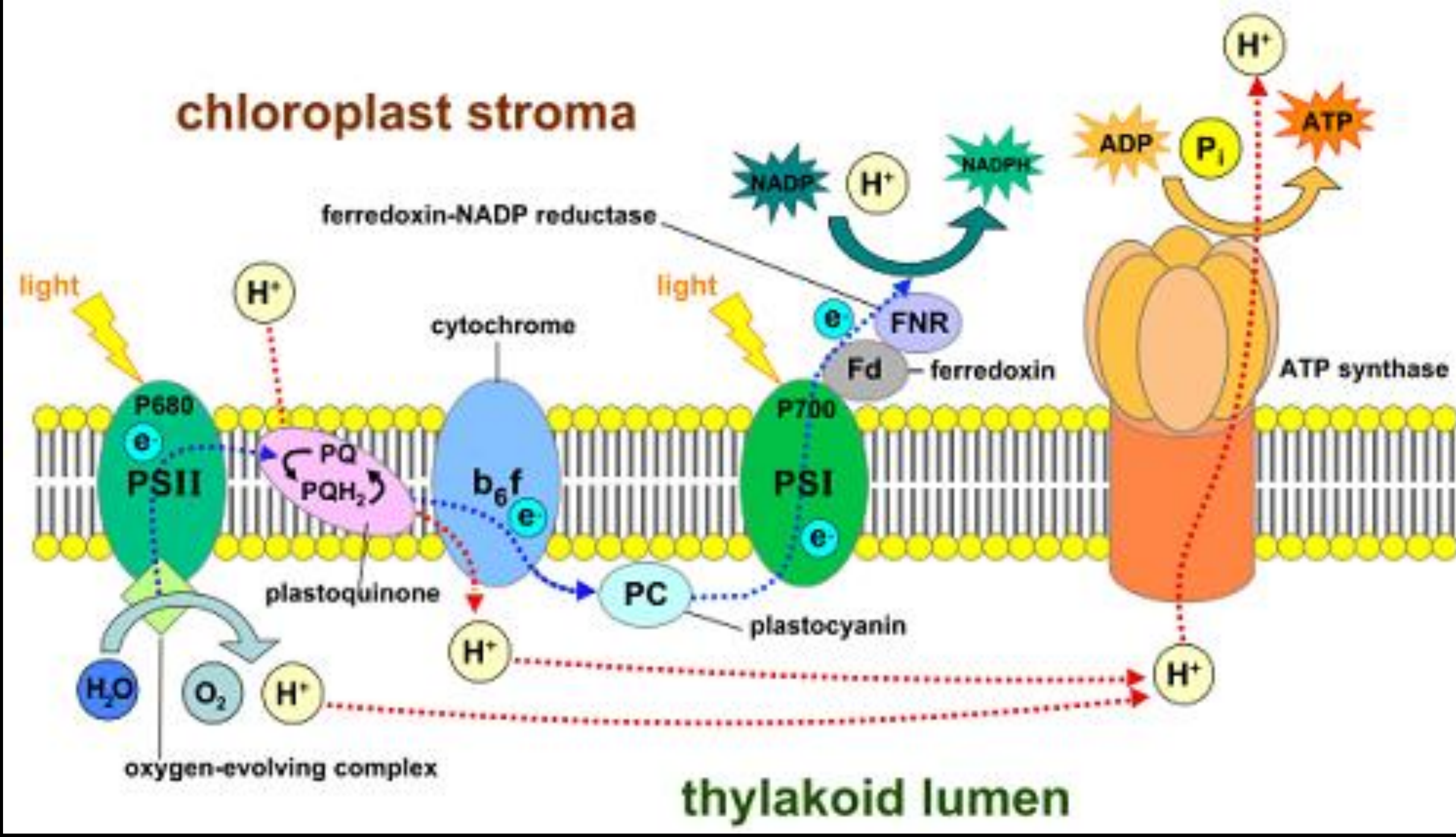
Vein – Site of Water Transport from root to leaves



Organization of a Thylakoid



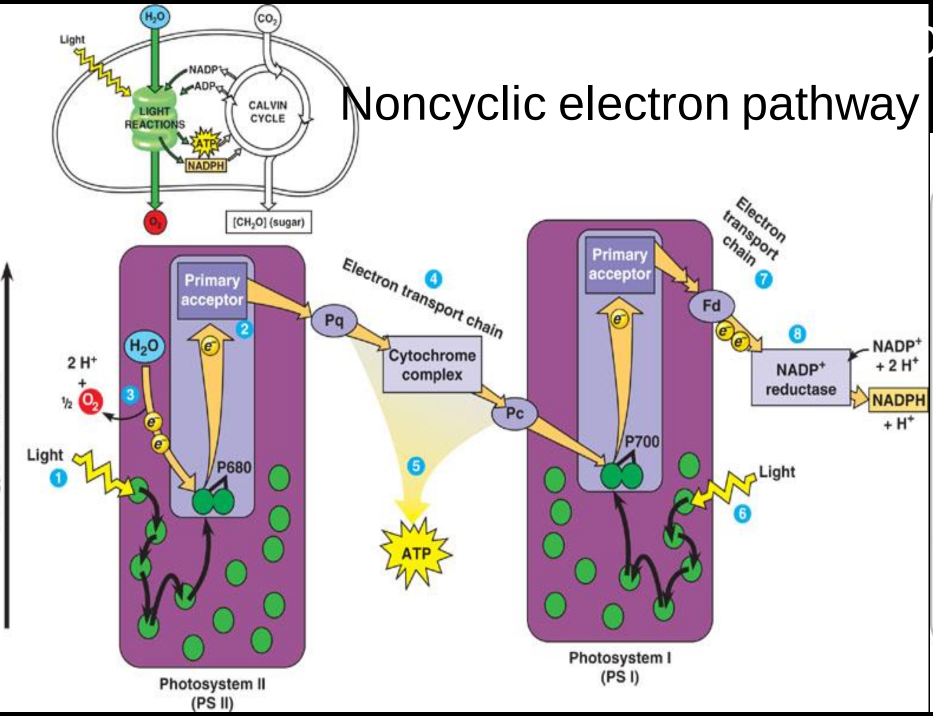
Light Reactions



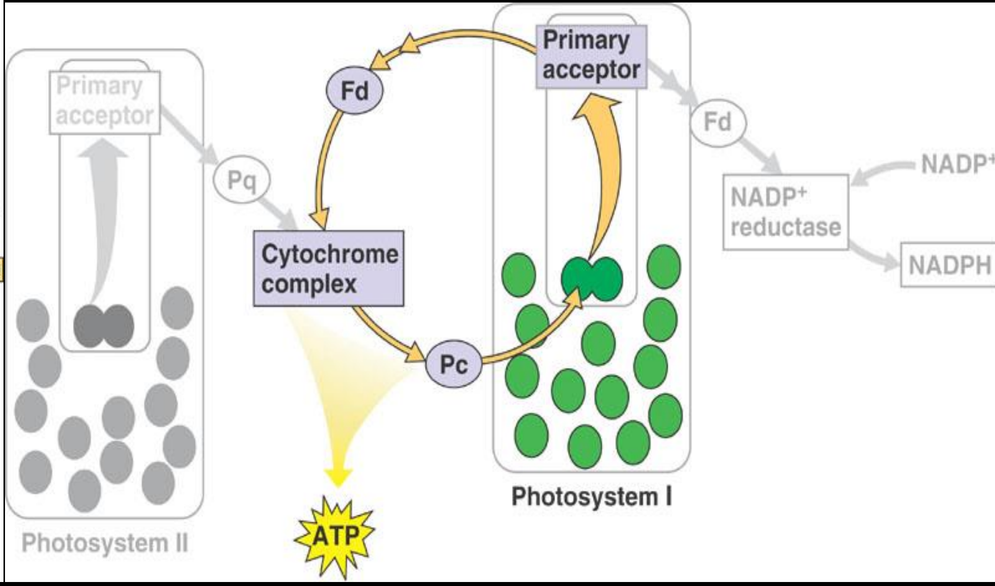
Photosynthetic Reactions: The Light Phase

- Light reactions consist of two alternate electron pathways:
  - Noncyclic electron pathway (PS2 → PS1)
  - Cyclic electron pathway (Only PS1)
- Capture light energy with photosystems
  - Pigment complex helps collect solar energy like an antenna
  - Occur in the thylakoid membranes
- Both pathways produce ATP

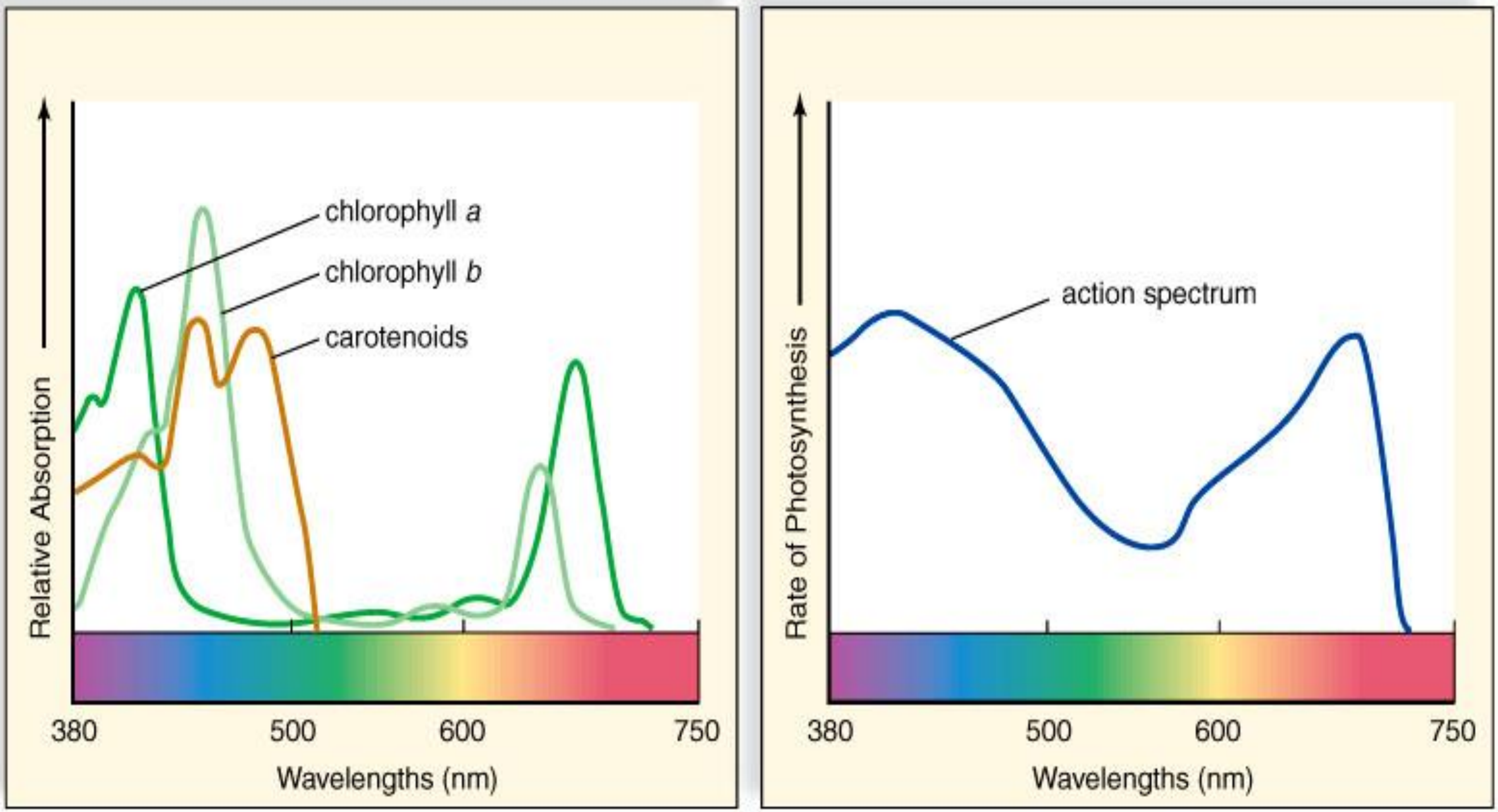
oduces NADPH



Cyclic electron pathway



Photosynthetic Pigments



a. The absorption spectrums for chlorophylls *a* and *b* and the carotenoids.

b. The action spectrum for photosynthesis.

Two phases of Photosynthesis

- **Light Reactions**
  - Occur in Thylakoid Membranes
  - Chlorophyll aborbs solar energy
  - Low-E e^-'s from H_2O are "excited" and passed to $NADP^+$ to form NADPH
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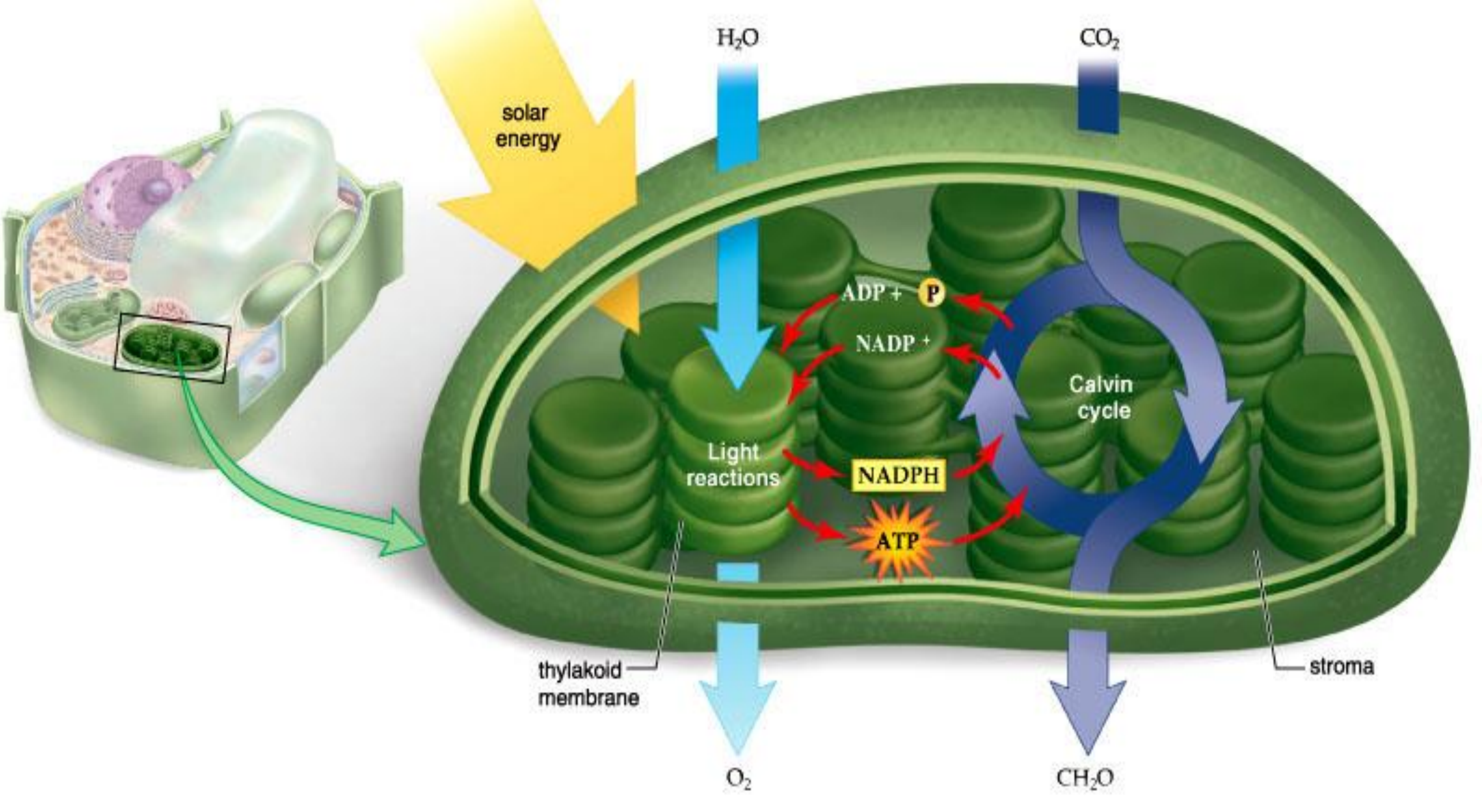
  - O_2 is released
- **Calvin Cycle** (aka "dark reactions")
  - Occurs in the Stroma
  - **Carbon Fixation** – CO_2 is reduced to a carbohydrate
  - Carbon is reduced by addition of the high-E e-'s from NADPH
  - This costs some ATP.

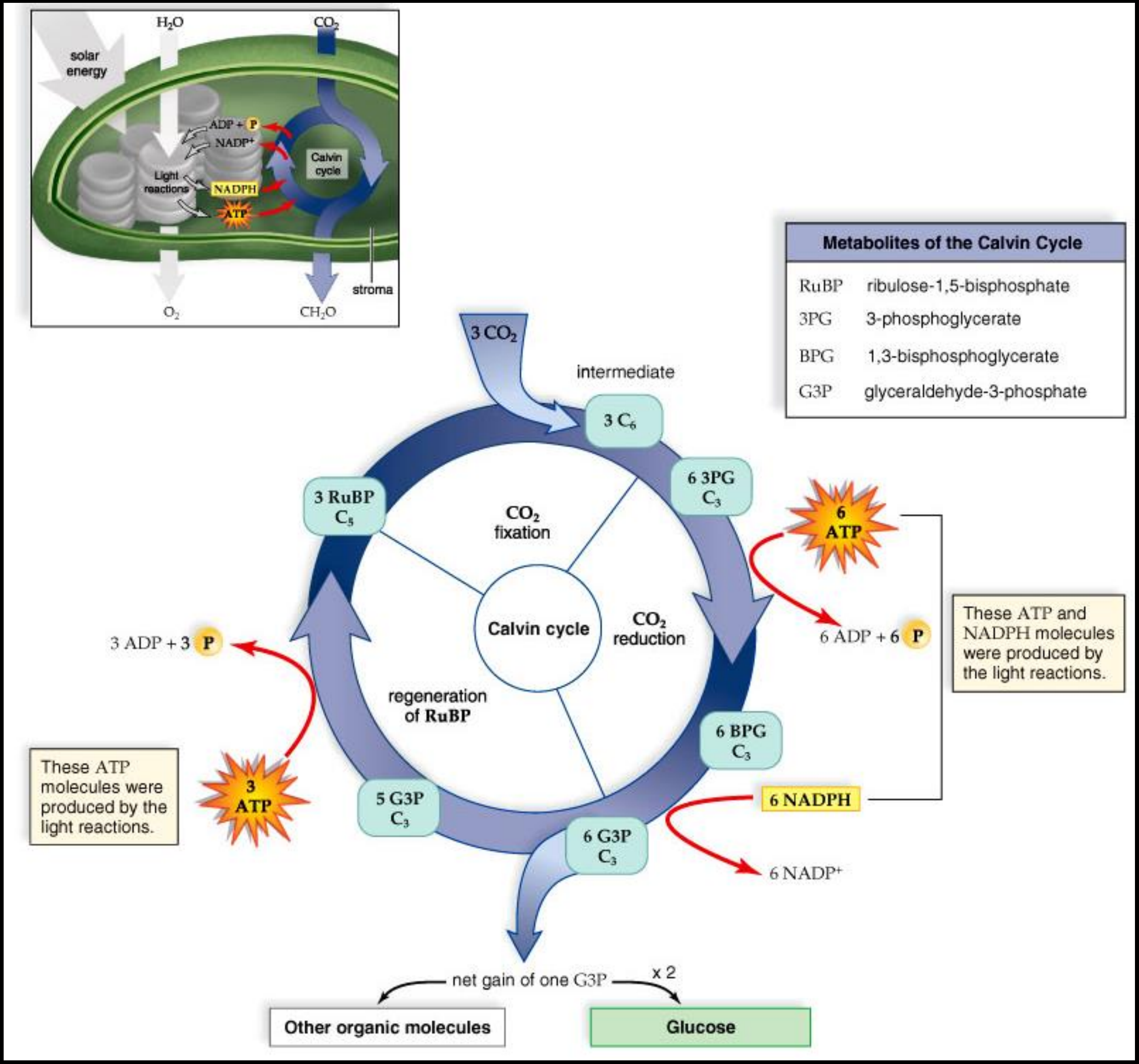
Photosynthesis Overview



Calvin Cycle Reactions: Overview of C3 Photosynthesis

- A cyclical series of reactions (similar citric acid cycle but **anabolic** not catabolic)
- Utilizes atmospheric carbon dioxide to produce carbohydrates
- Known as C3 photosynthesis
- Involves three stages:
  - Carbon dioxide fixation
  - Carbon dioxide reduction
  - Ribulose bisphosphate (RuBP) Regeneration

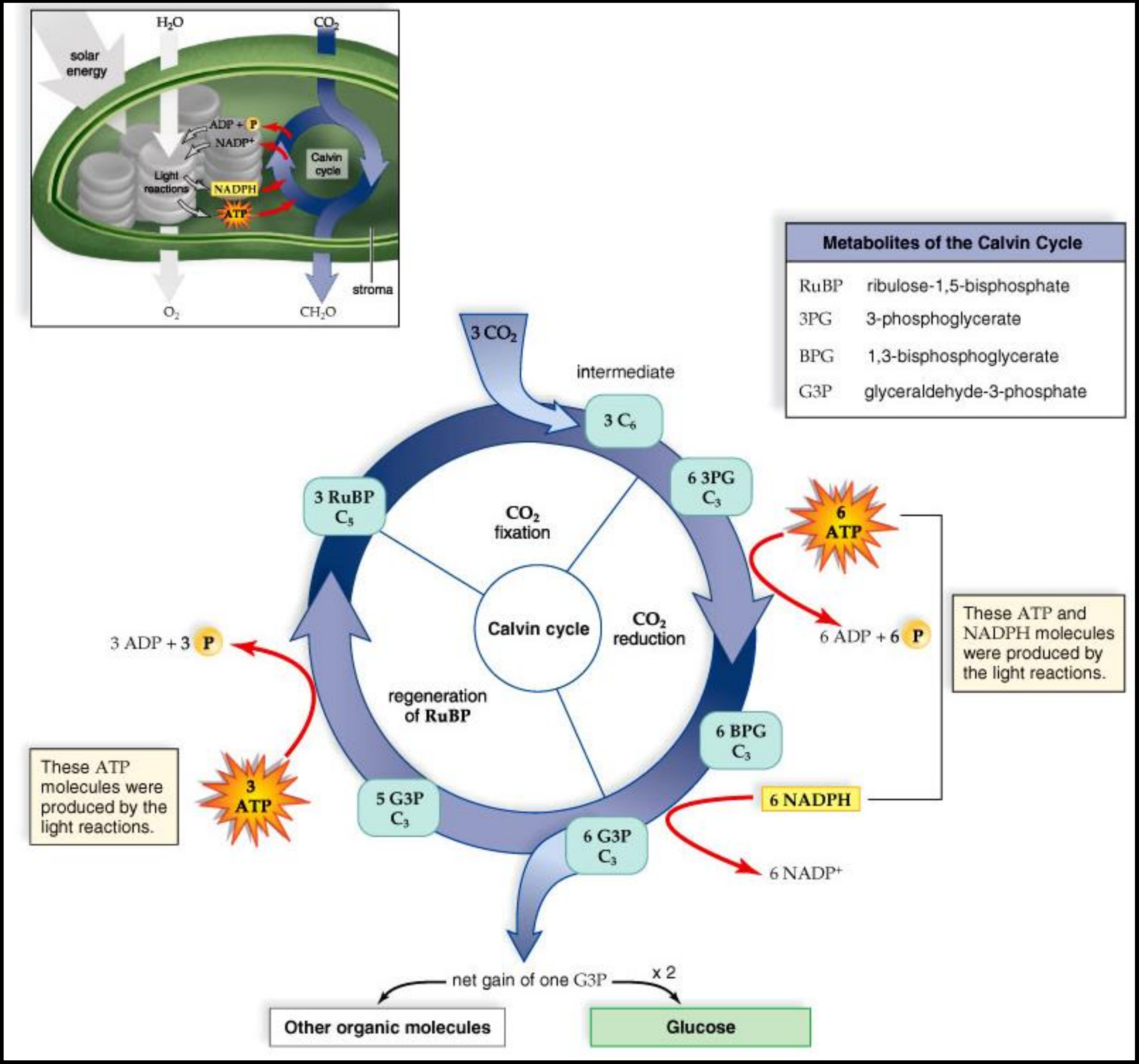
The Calvin Cycle: Fixation of CO_2

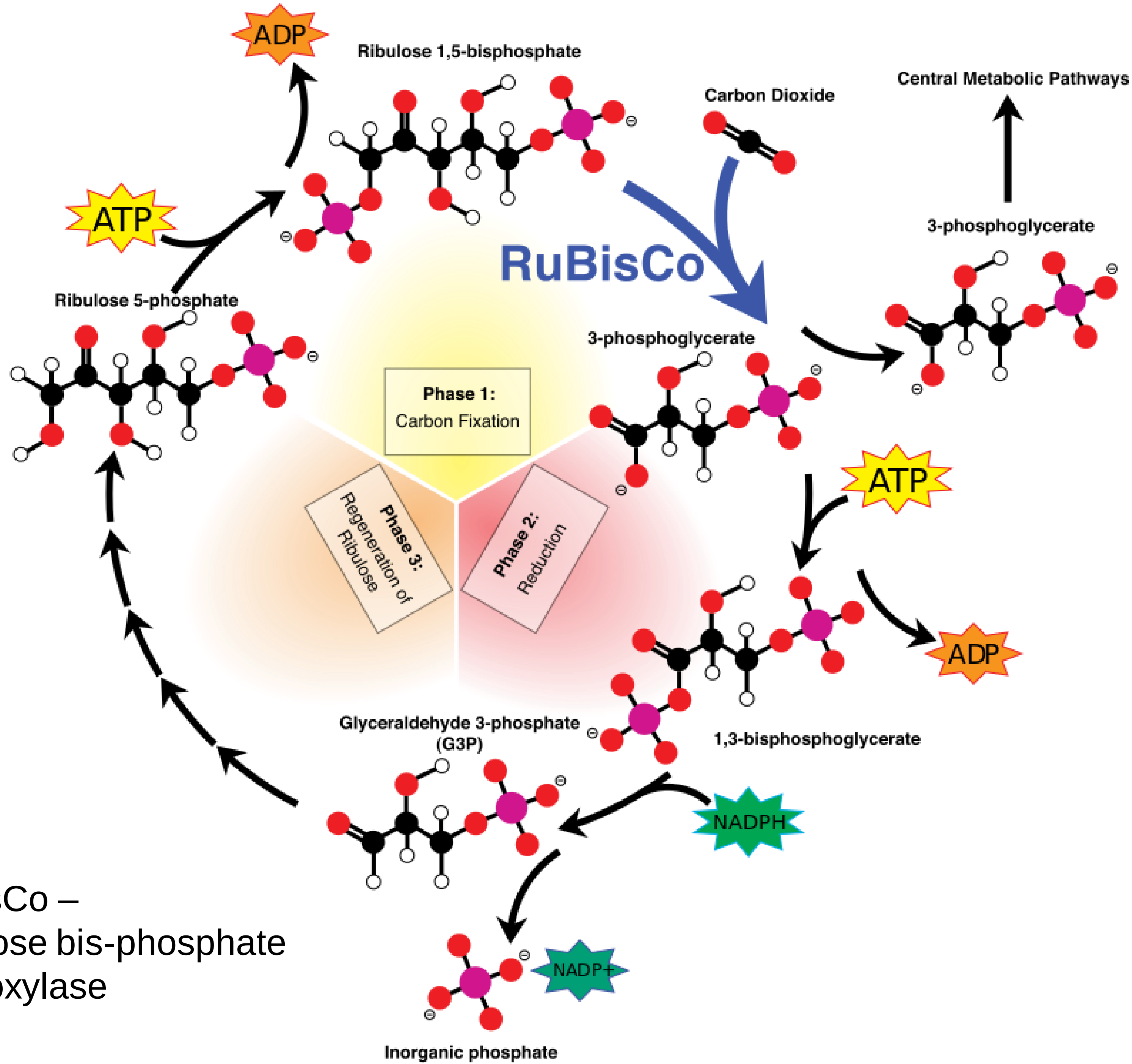


Calvin Cycle Reactions:
Carbon Dioxide Fixation

- CO_2 is attached to 5-carbon RuBP (Ribulose bis-phosphate) molecule
  - Result in a 6-carbon molecule
  - This splits into two 3-carbon molecules (3PG) 3-Phosphoglycerate
  - Reaction accelerated by RuBP Carboxylase (Rubisco-Most abundant protein in chloroplasts, and possibly EARTH)
  - CO_2 now “fixed” because it is part of a carbohydrate

The Calvin Cycle: Fixation of CO_2

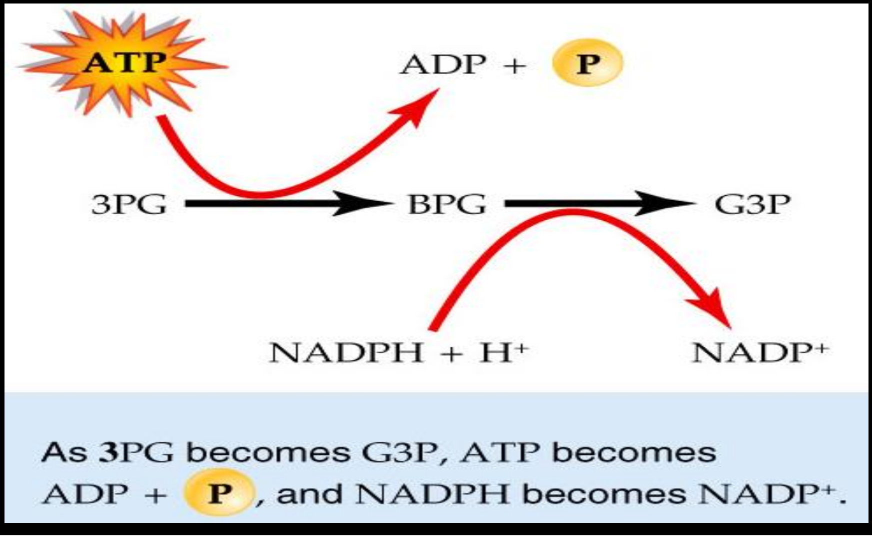


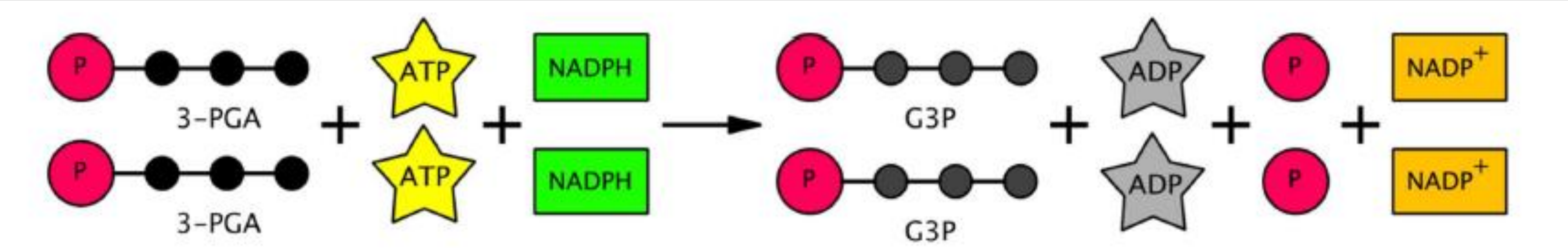


RuBisCo –
Ribulose bis-phosphate
Carboxylase

Carbon Dioxide Reduction

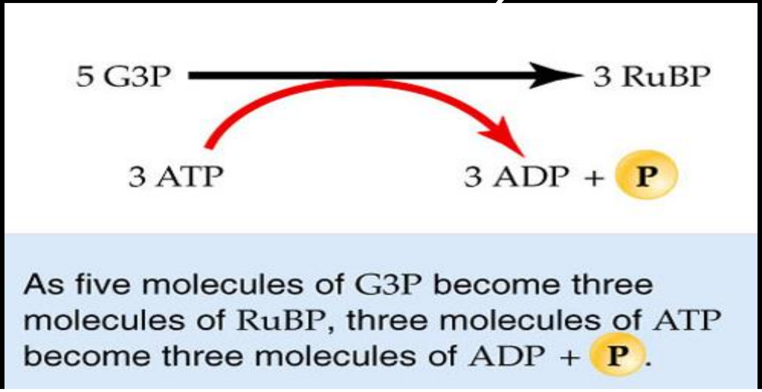
- 3PG reduced to BPG (1,3 bis-phospho glycerate)
- BPG then reduced to G3P (glyceral-aldehdyde 3-phosphate)
- Utilizes NADPH and some ATP produced in light reactions

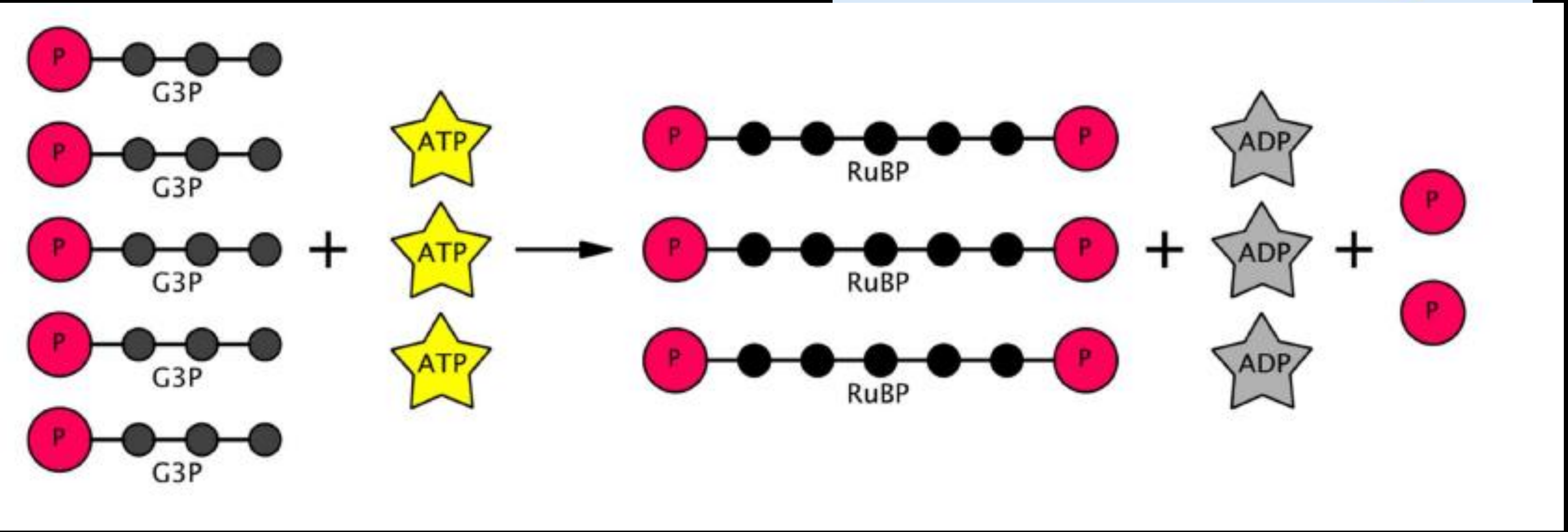




Regeneration of RuBP

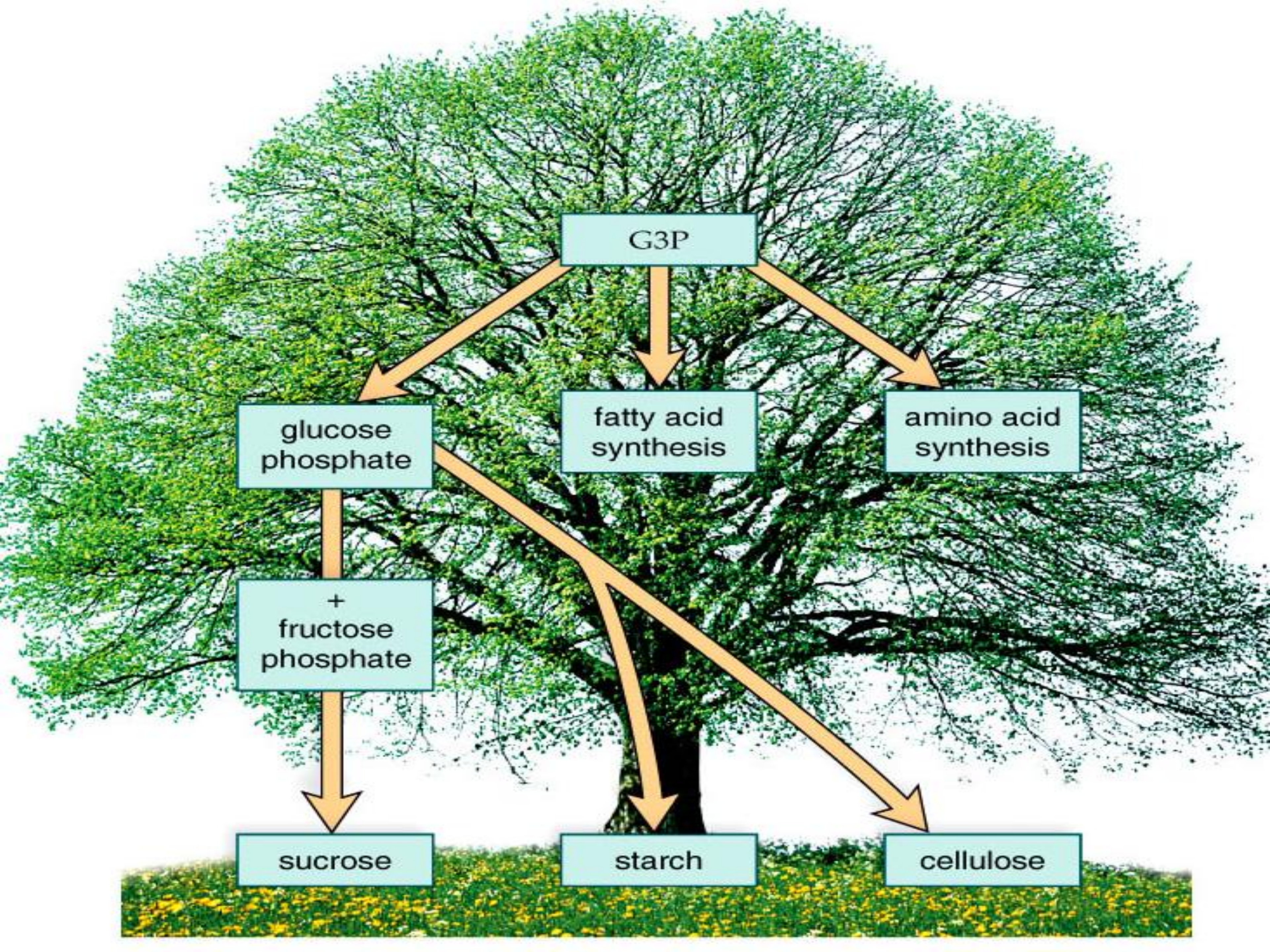
- RuBP used in CO_2 fixation must be replaced
- Every three turns of Calvin Cycle,
  - Five G3P (a 3-carbon molecule) used
  - To remake three RuBP (a 5-carbon molecule)
  - 5 X 3 = 3 X 5

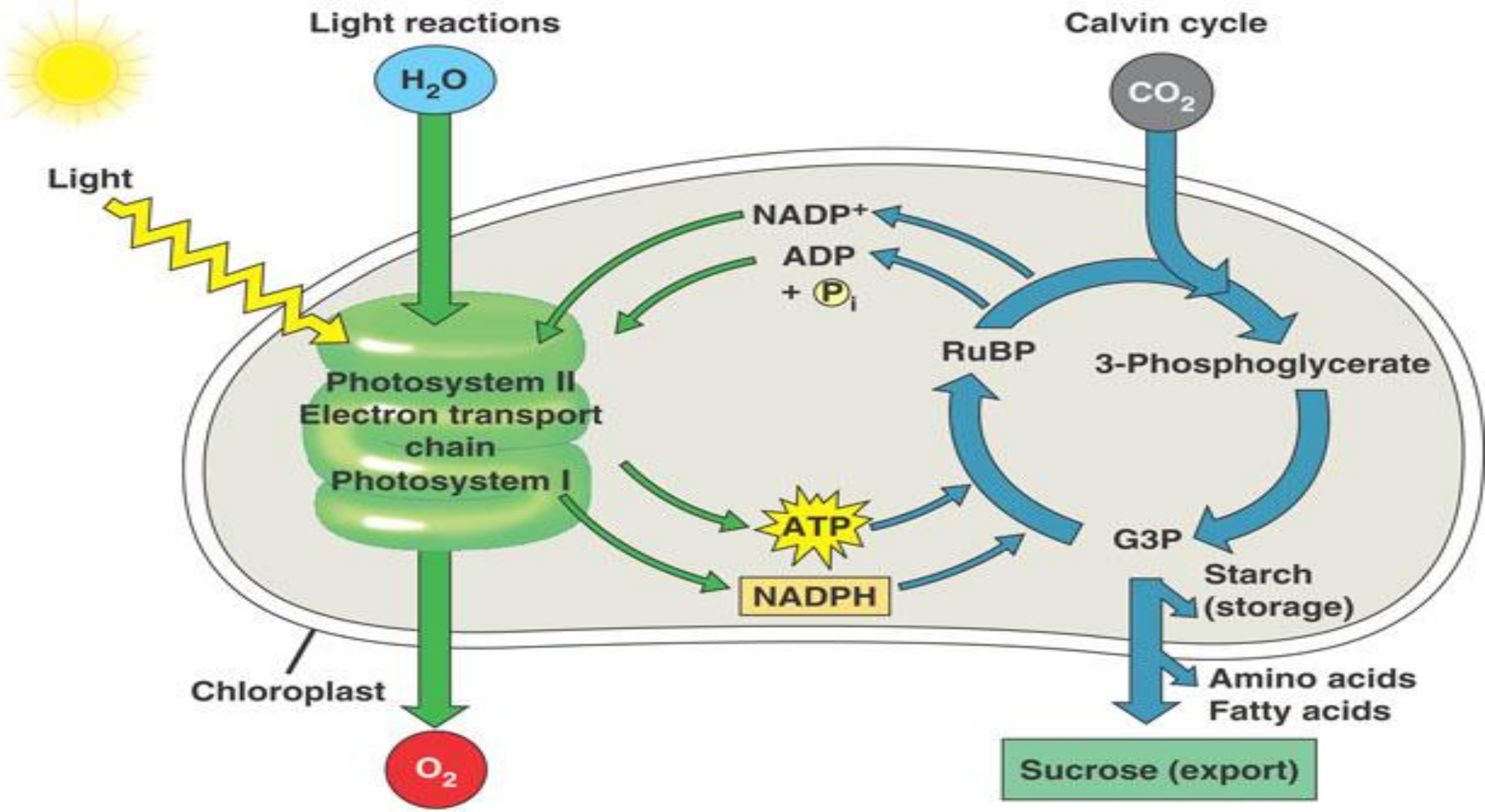




Importance of Calvin Cycle

- G3P (glyceraldehyde-3-phosphate) can be converted to many other molecules
- The hydrocarbon skeleton of G3P can form
  - Fatty acids and glycerol to make plant oils
  - Glucose phosphate (simple sugar)
  - Fructose (which with glucose = sucrose)
  - Starch and cellulose
  - Amino acids


G3P
glucose phosphate
fatty acid synthesis
amino acid synthesis
+
fructose phosphate
sucrose
starch
cellulose



Light reactions:

- Are carried out by molecules in the thylakoid membranes
- Convert light energy to the chemical energy of ATP and NADPH
- Split H_2O and release O_2 to the atmosphere

Calvin cycle reactions:

- Take place in the stroma
- Use ATP and NADPH to convert CO_2 to the sugar G3P
- Return ADP, inorganic phosphate, and $NADP^+$ to the light reactions

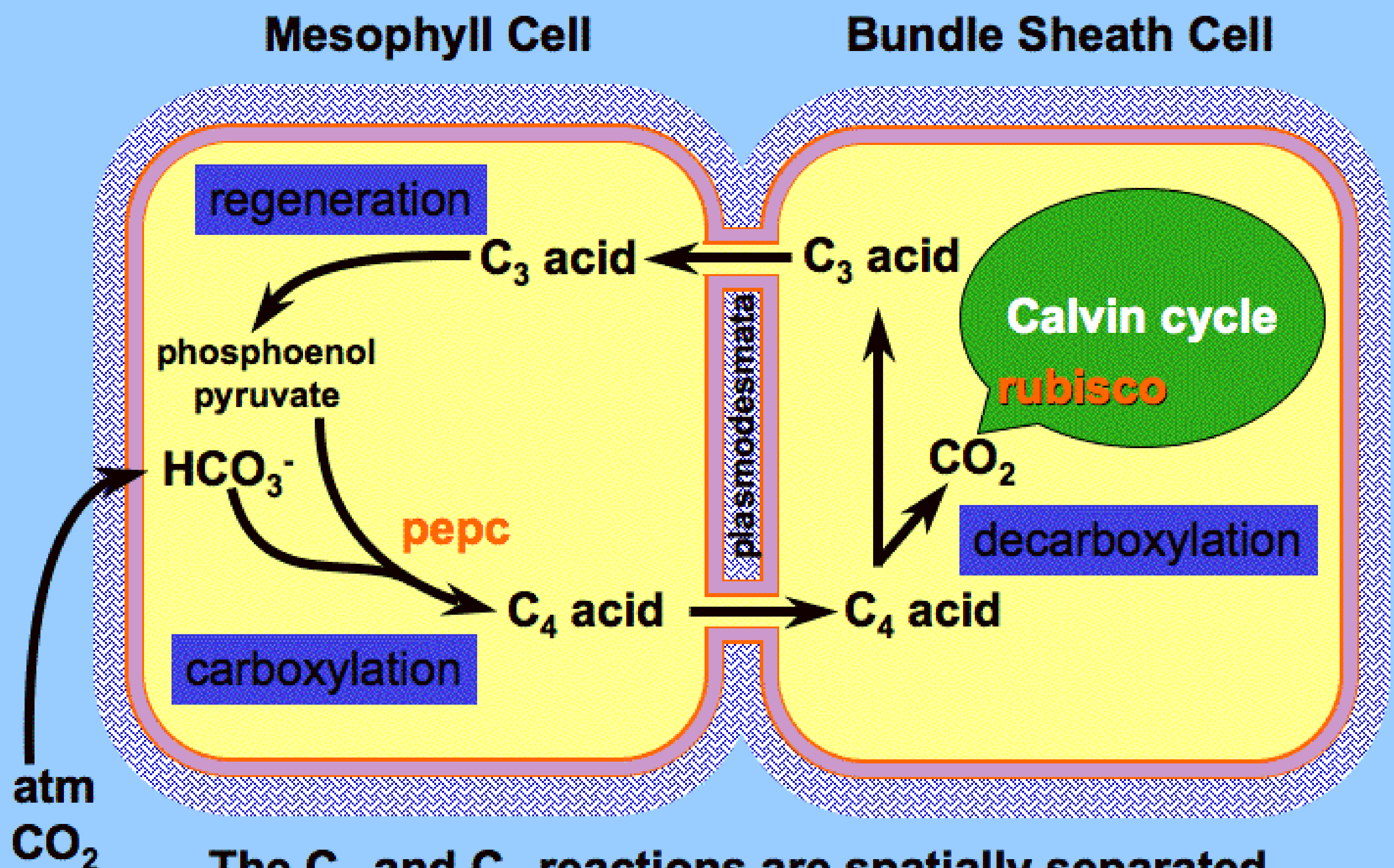
C_4 Photosynthesis

- In hot, dry climates
  - Stomata must close to avoid wilting
  - CO_2 decreases and O_2 increases
  - O_2 starts combining with RuBP instead of CO_2
  - Photorespiration, a problem solve in C_4 plants
- In C_4 plants
  - Fix CO_2 to PEP (phospho-enol pyruvate) a C_3 molecule

$$PEP + CO_2 \rightarrow \text{oxaloacetate} \ (C_4 \ \text{molecule})$$

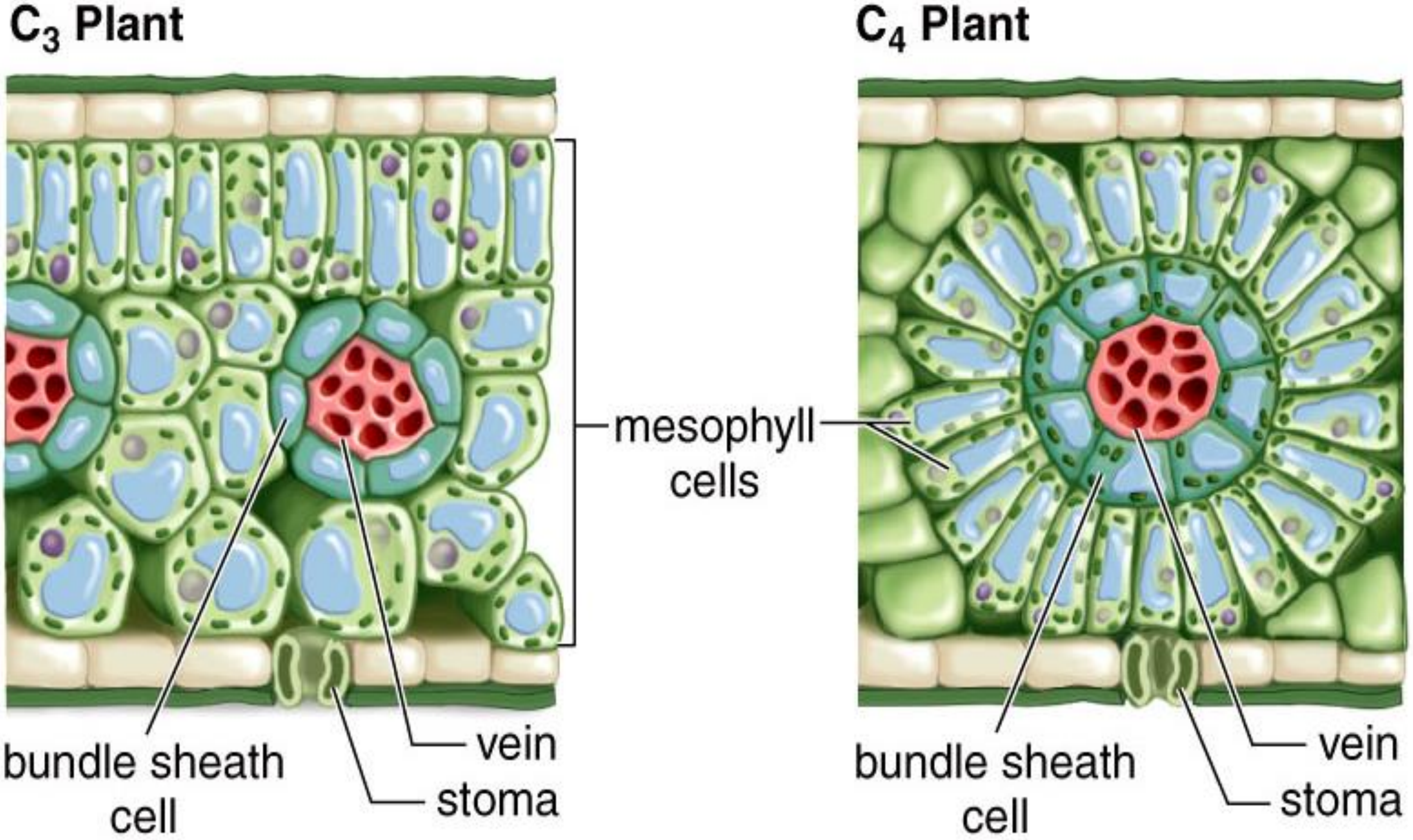
  - The result is oxaloacetate, a C_4 molecule
  - In hot & dry climates
    - Avoid photorespiration
    - Net productivity about 2-3 times C_3 plants
  - In cool, moist, can't compete with C_3

C_4 Photosynthesis: The first fixation is a 4-carbon compound



The C_4 and C_3 reactions are spatially separated

Chloroplast distribution in C_4 vs. C_3 Plants



CO_2 Fixation in C_4 vs. C_3 Plants

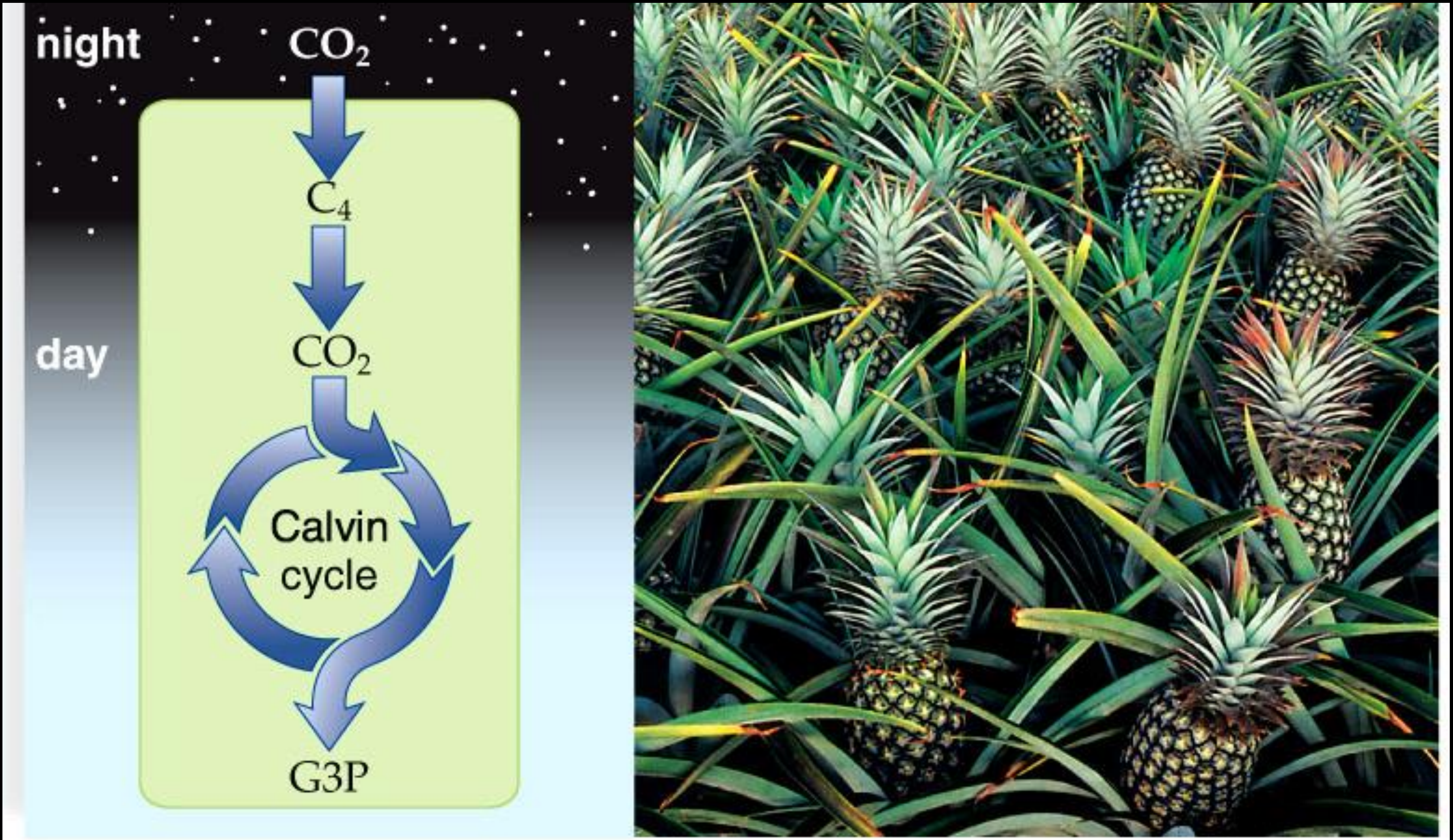
a. CO_2 fixation in a C_3 plant, blue columbine, *Aquilegia caerulea*

b. CO_2 fixation in a C_4 plant, corn, *Zea mays*

CAM Photosynthesis

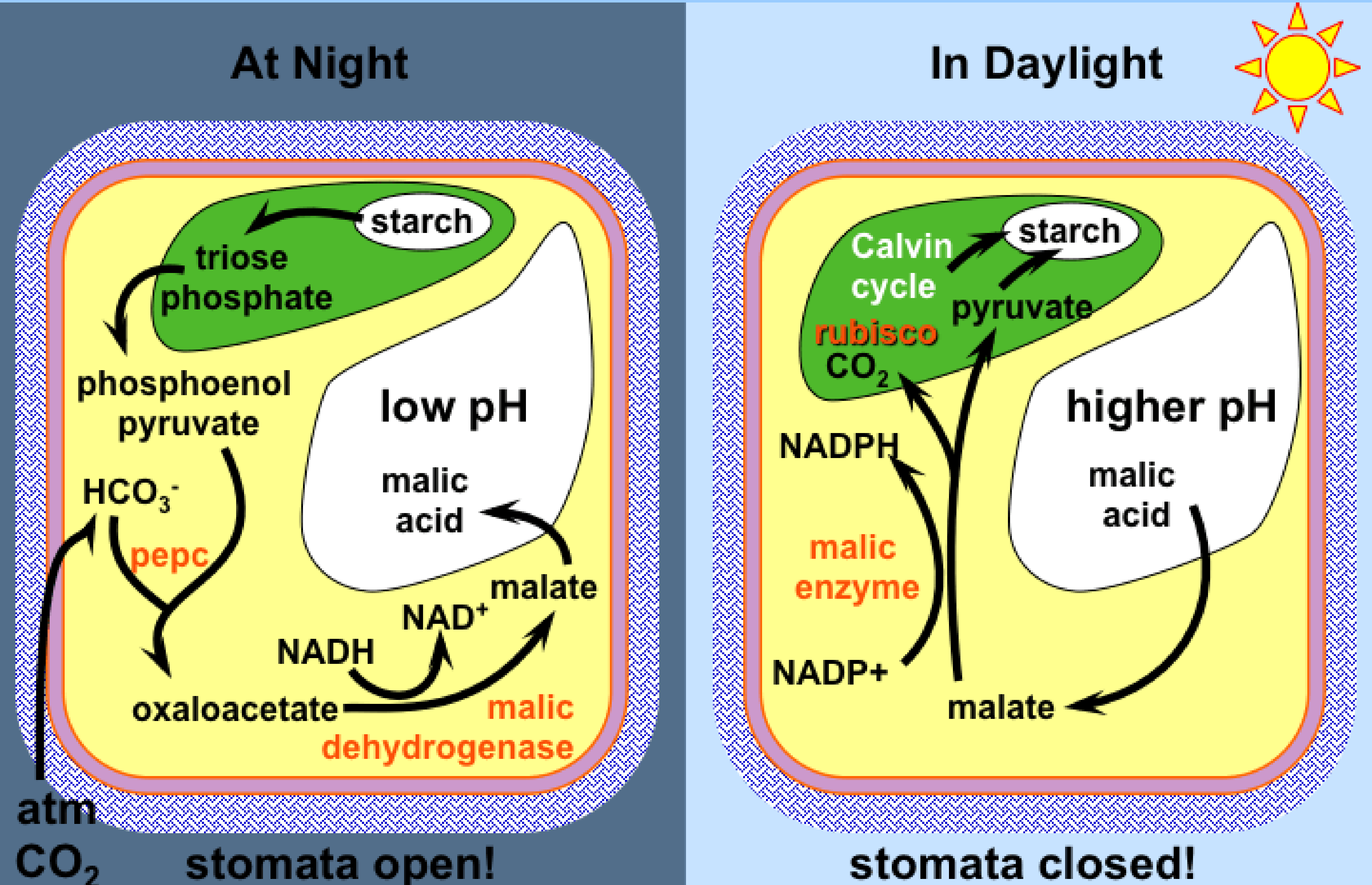
- **Crassulacean-Acid Metabolism**
  - CAM plants partition carbon fixation by time
    - During the night
      - CAM plants fix CO_2
      - Forms C_4 molecules,
      - Stored in large vacuoles
    - During daylight
      - NADPH and ATP are available
      - Stomata closed for water conservation
      - C_4 molecules release CO_2 to Calvin cycle

CO_2 Fixation in a CAM Plant



CO_2 fixation in a CAM plant, pineapple, *Ananas comosus*

CAM Photosynthesis: Crassulacean Acid Metabolism



The C_4 and C_3 reactions are temporally separated

Climatic Adaptation: Photosynthesis

- Each method of photosynthesis has advantages and disadvantages
- Depends on the climate
- C_4 plants most adapted to:
  - high light intensities
    - high temperatures
    - Limited rainfall
- C_3 plants better adapted to
    - Cold (below 25C)
    - High moisture
- CAM plants better adapted to extreme aridity
  - CAM occurs in 23 families of flowering plants
  - Also found among nonflowering plants

ecology Focus

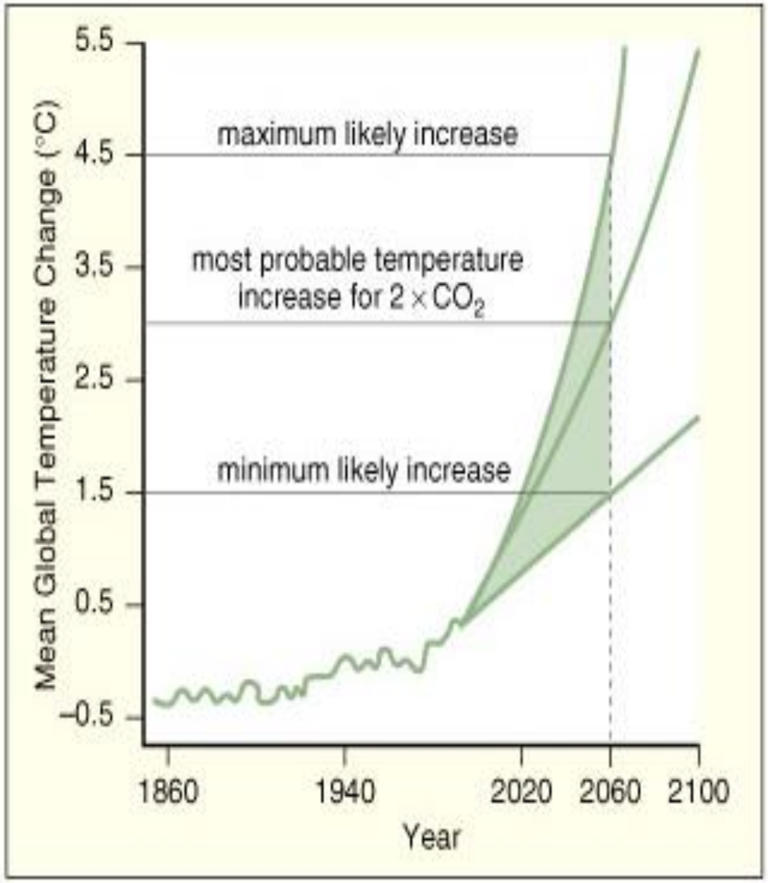
Tropical Rain Forests

- Equatorial; Temp>26ºC; Rainfall>200cm & uniform
- Most plants woody; many vines and epiphytes; little or no undergrowth
- Contribute greatly to CO_2 uptake, slowing global warming
  - Development has reduced them from 14% to 6% of Earth's surface
  - Deforestation adds 20-30% of atmospheric CO_2, but also removes CO_2 sink
  - Increasing temps also reduce productivity

ecology Focus

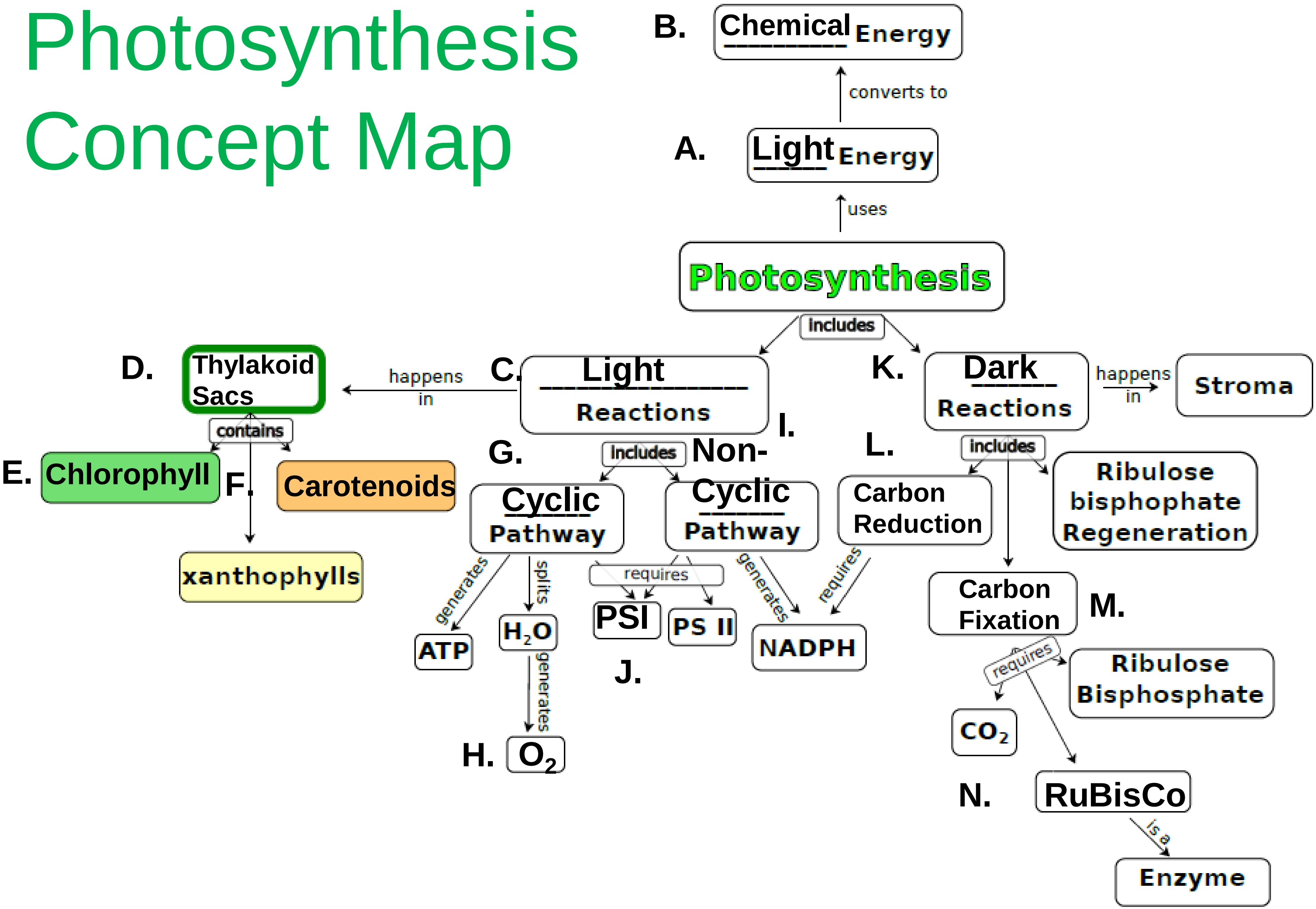
Global Warming and Tropical Rain Forests

a.



b.

Photosynthesis Concept Map



RuBisCo – Ribulose Bisphosphate Carboxylase