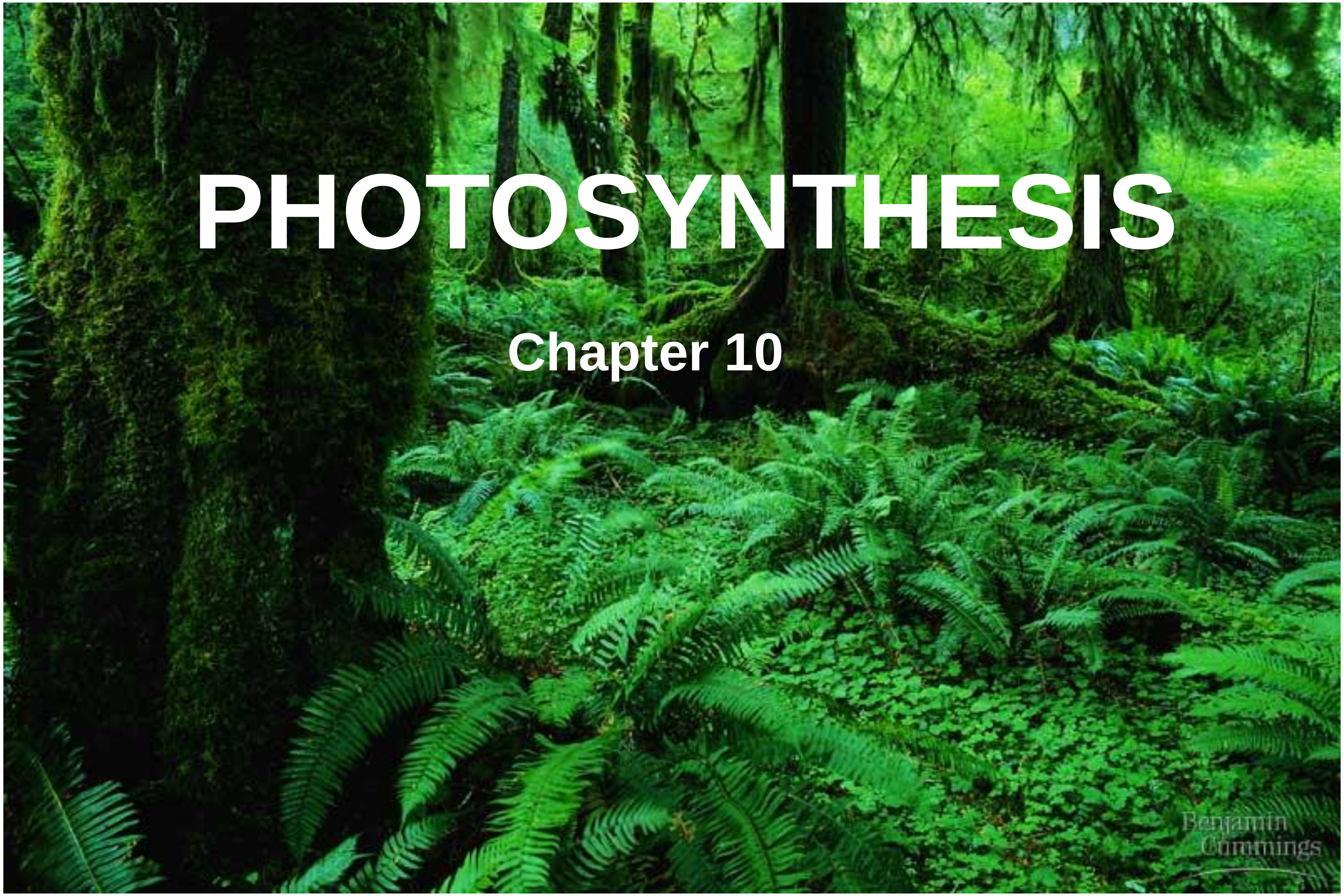
PHOTOSYNTHESIS

Chapter 10



Modes of Nutrition

- **Autotrophs** – "self-feeders"
  - – Capture free energy from physical sources in the environment
    - Photosynthetic organisms = sunlight
    - Chemosynthetic organisms = small inorganic molecules (occurs in absence of oxygen)
  - – Produce organic molecules from CO_2 and other inorganic raw materials from the environment
  - – Are PRODUCERS of the biosphere

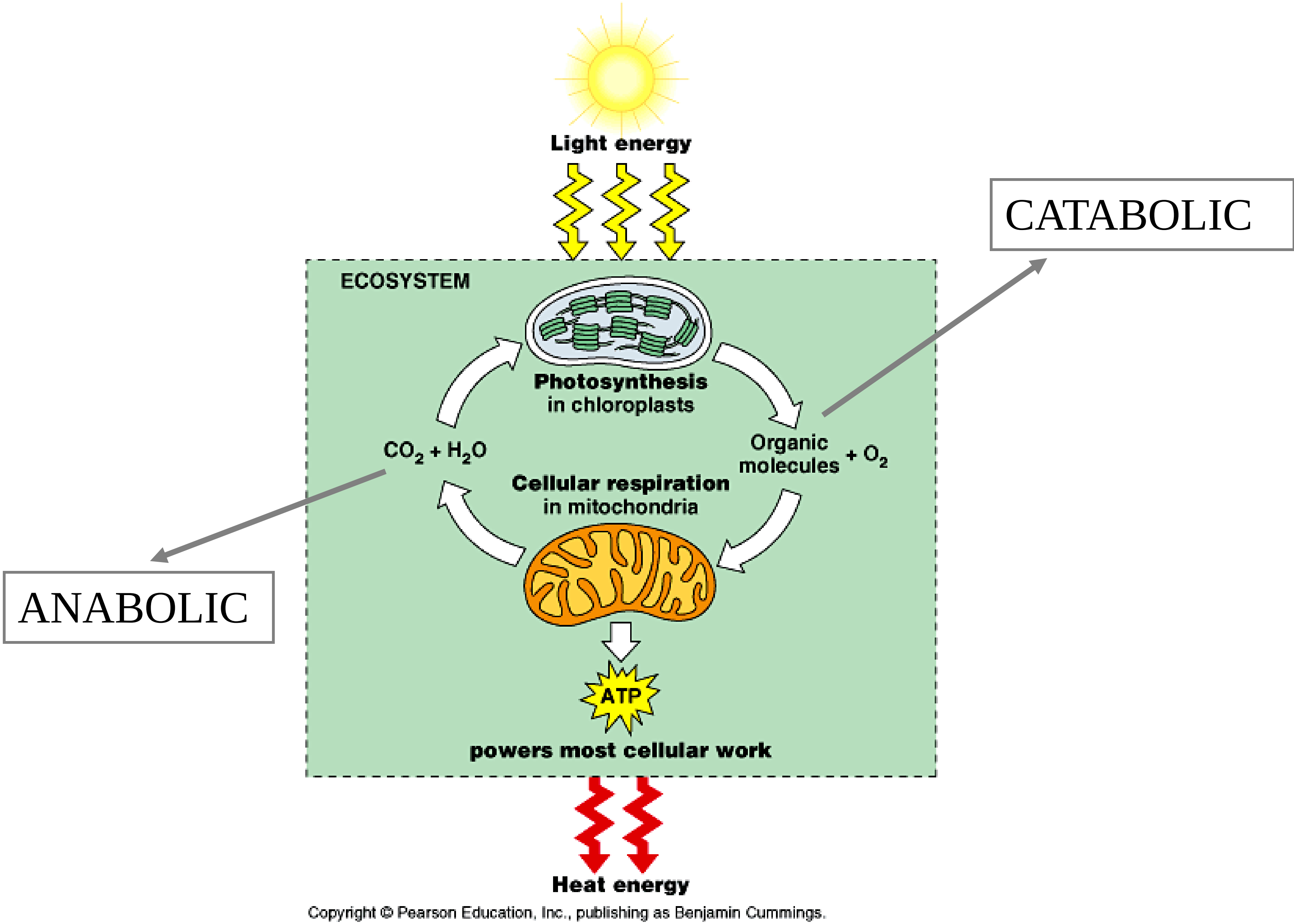
Modes of Nutrition

- **Heterotrophs** – "consumers"
  - Captures free energy present in carbon compounds produced by other organisms
  - Metabolize carbohydrates, lipids, and proteins by hydrolysis as sources of free energy
  - CONSUMERS of the biosphere

Photosynthesis & Cellular Respiration

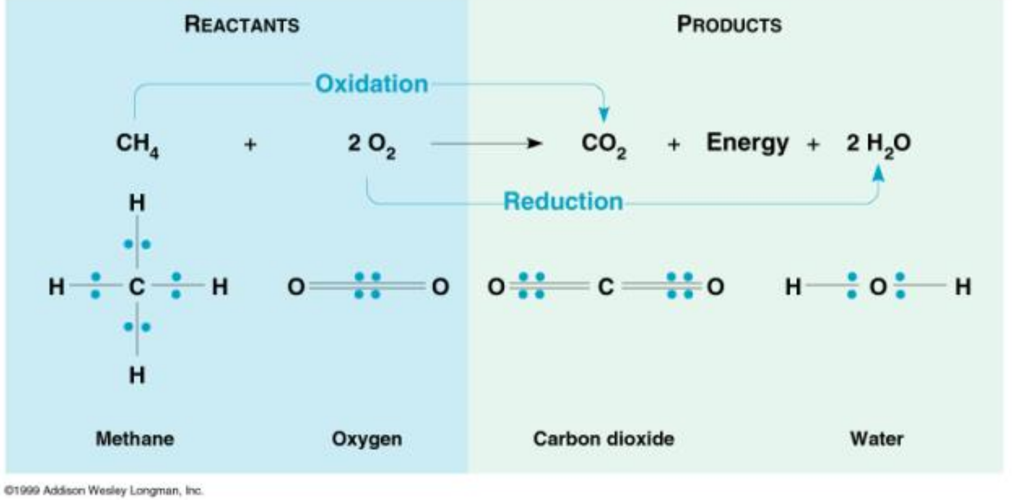
- Photosynthesis is the conversion of **light energy** into **chemical energy**

- Cellular respiration is the harvesting of **ENERGY** in the **chemical bonds** of **glucose**


Light energy
ECOSYSTEM
Photosynthesis
in chloroplasts
$CO_2 + H_2O$
Organic
molecules
$+ O_2$
Cellular respiration
in mitochondria
ATP
powers most cellular work
Heat energy
Copyright © Pearson Education, Inc., publishing as Benjamin Cummings.
CATABOLIC
ANABOLIC

Oxidation-reduction (Redox) Reactions

- Oxidation is electron loss; Reduction is electron gain
  - OIL RIG (adding electron reduces + charge)
- Reducing agent is electron donor and Oxidizing agent is electron acceptor



Structure of a plant

- How they obtain the raw materials for photosynthesis:
  - **Sunlight**
    - Leaves = solar collectors
  - **CO2**
    - Stomata = gas exchange
  - **H2O**
    - Uptake from roots
  - **Nutrients**
    - Uptake from roots

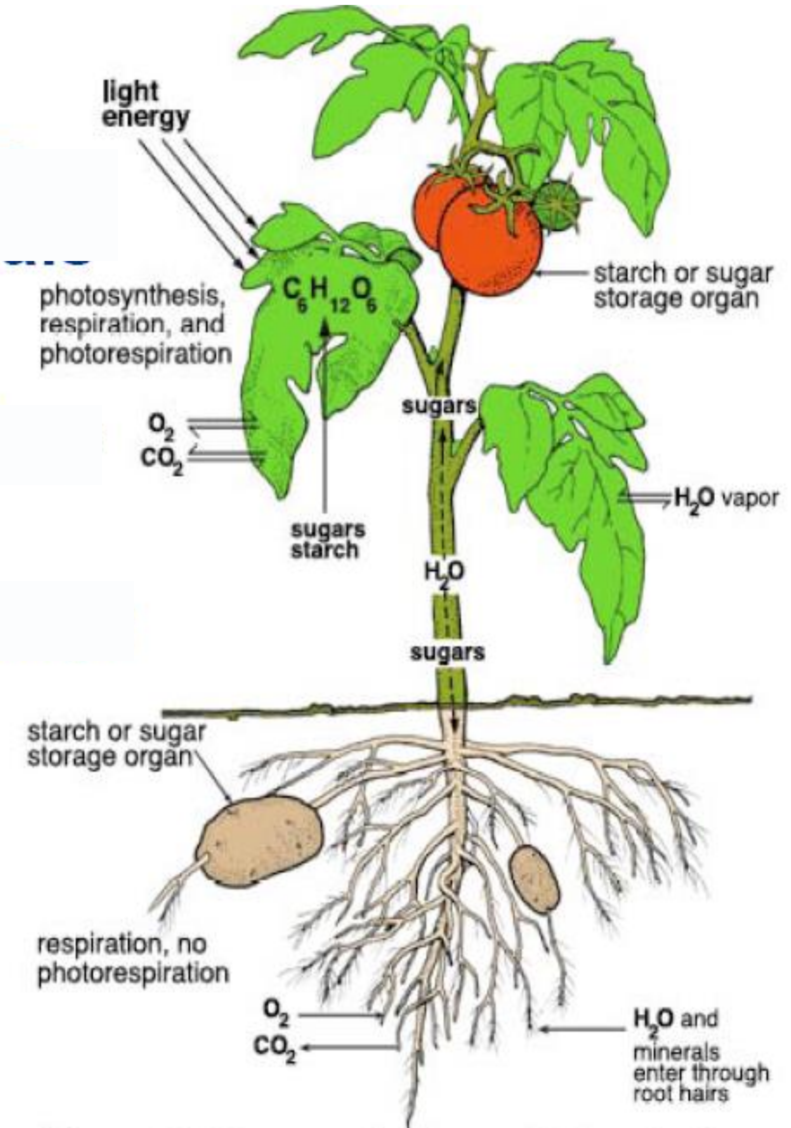
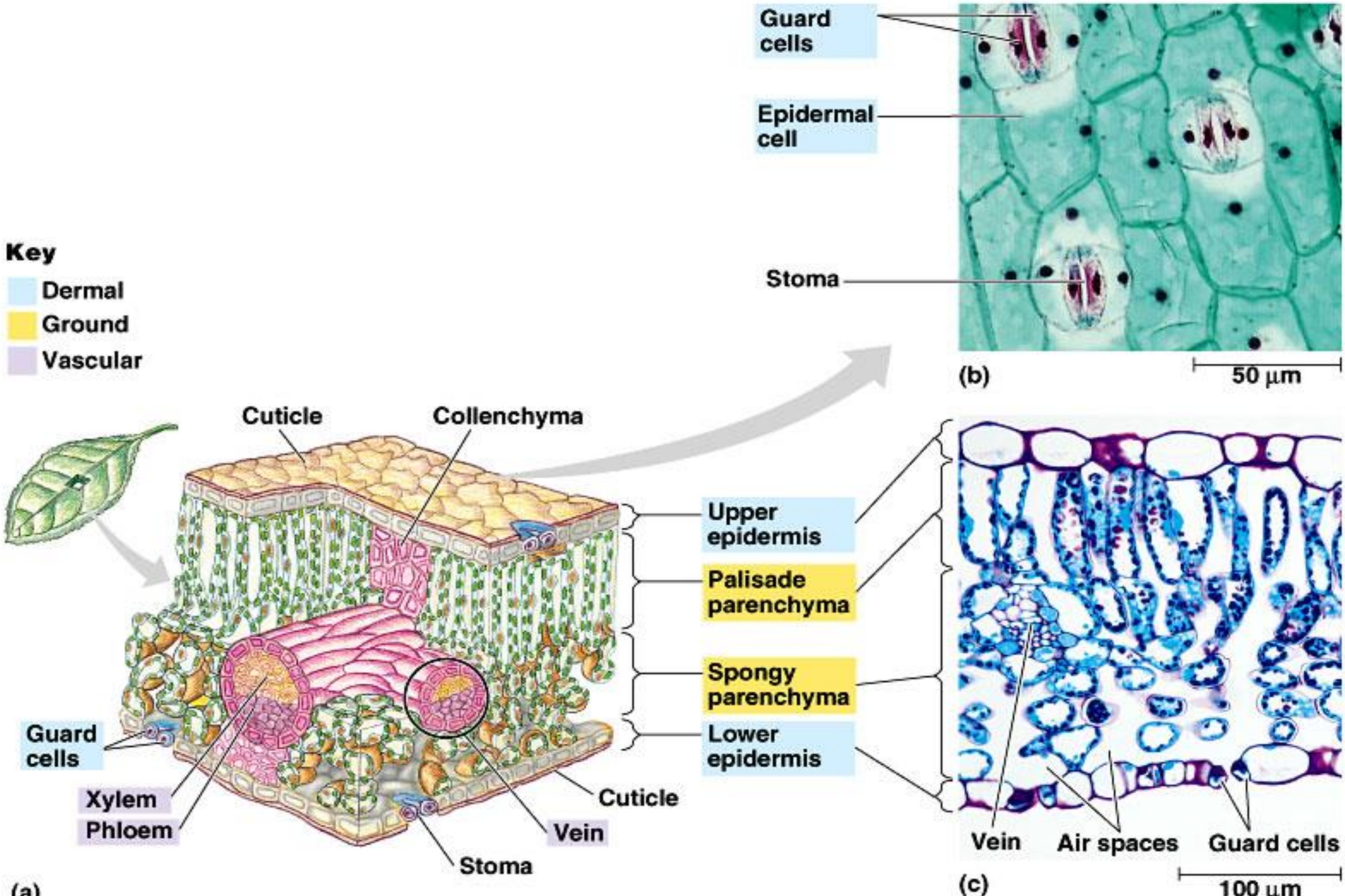


Figure 24. Photosynthesis, respiration, leaf water exchange, and translocation of sugar (photosynthate) in a plant.


Key
Dermal
Ground
Vascular
Guard cells
Epidermal cell
Stoma
(b)
50 µm
Cuticle
Collenchyma
Upper epidermis
Palisade parenchyma
Spongy parenchyma
Lower epidermis
Guard cells
Xylem
Phloem
Cuticle
Vein
Stoma
(a)
Vein
Air spaces
Guard cells
(c)
100 µm

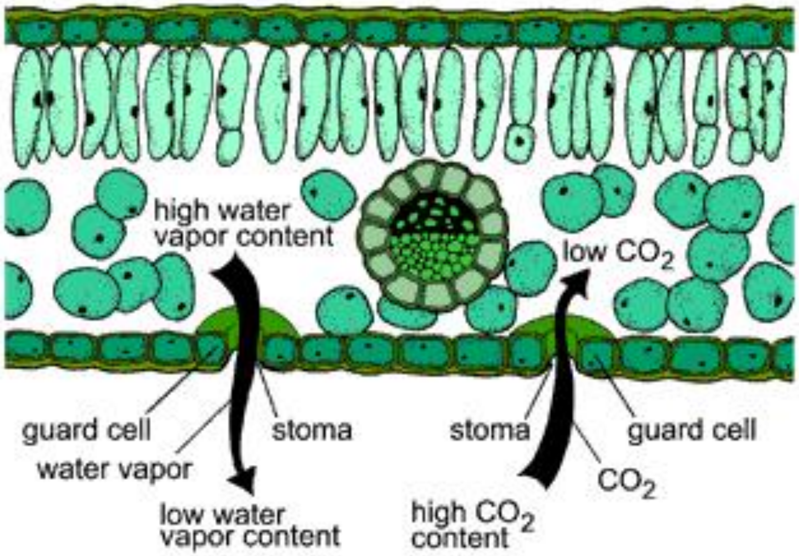
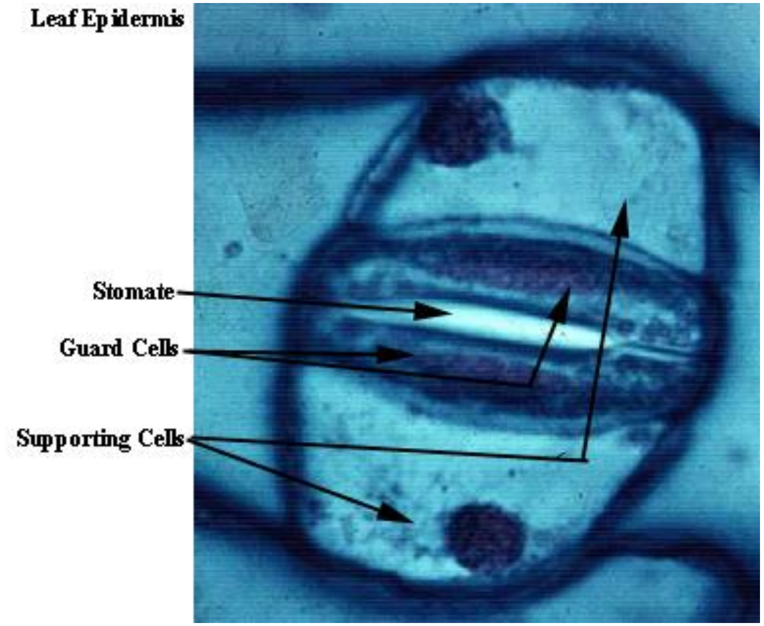
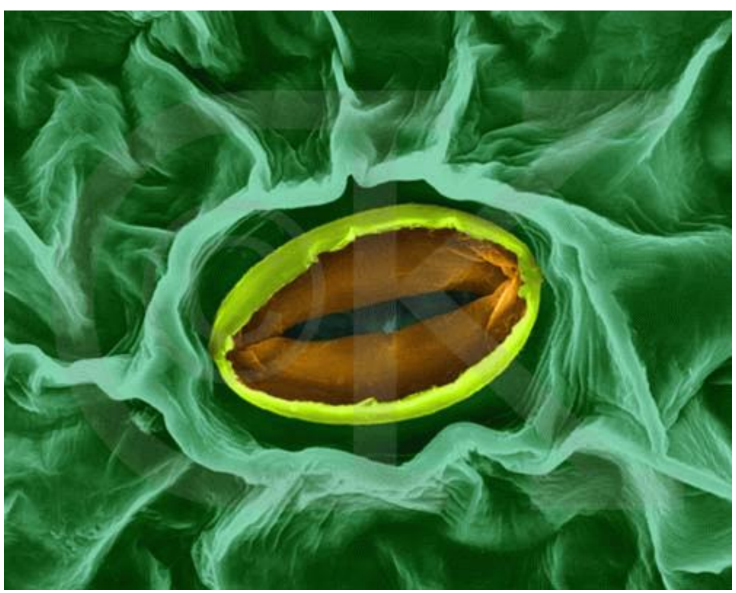
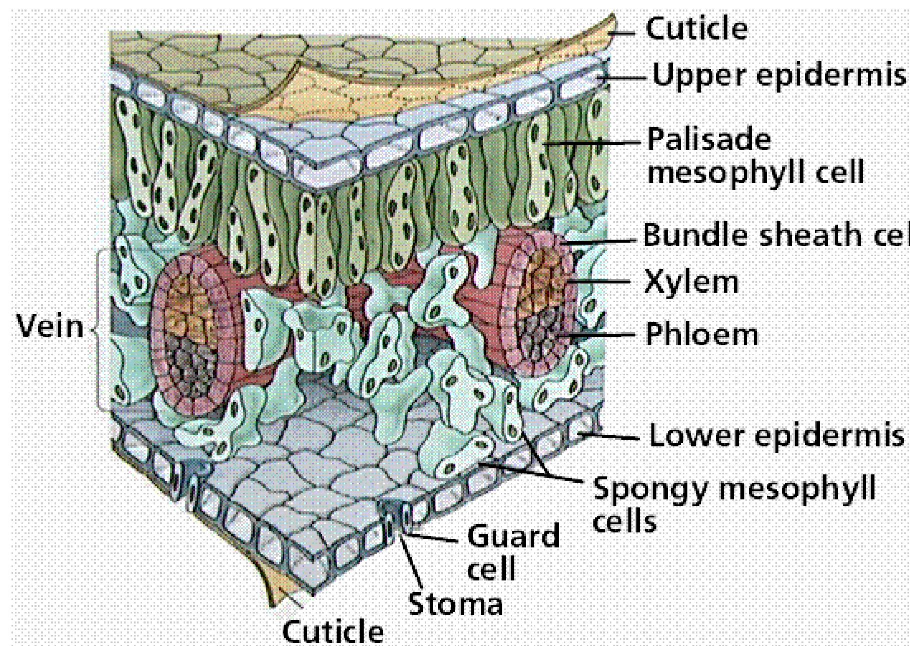


Figure 25. Stomata open to allow carbon dioxide (CO_2) to enter a leaf and water vapor to leave.

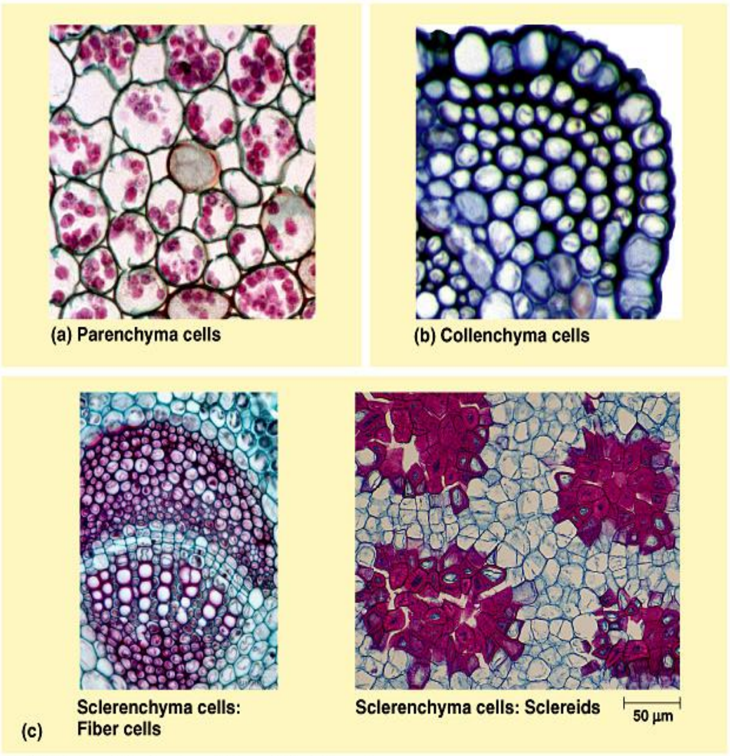






Plant Tissue Cell Types

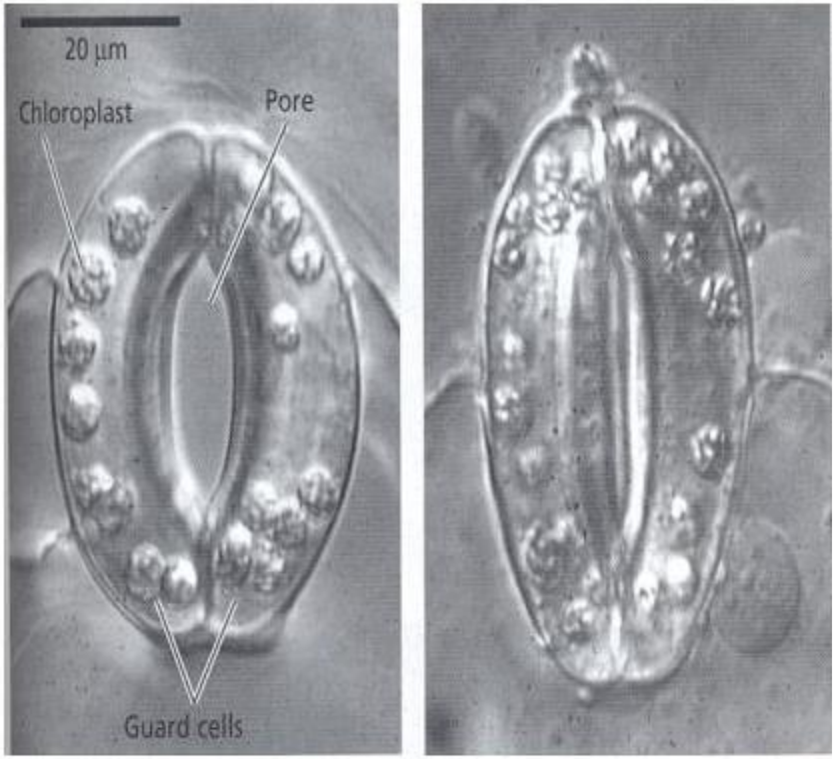
- <u>Parenchyma</u>
  - primary walls thin and flexible; no secondary walls; large central vacuole; most metabolic functions of plant (chloroplasts)
- <u>Collenchyma</u>
  - unevenly thick primary walls used for plant support (no secondary walls ; no lignin)
- <u>Sclerenchyma</u>
  - support element strengthened by secondary cell walls with lignin (may be dead; xylem cells); fibers and sclereids for support

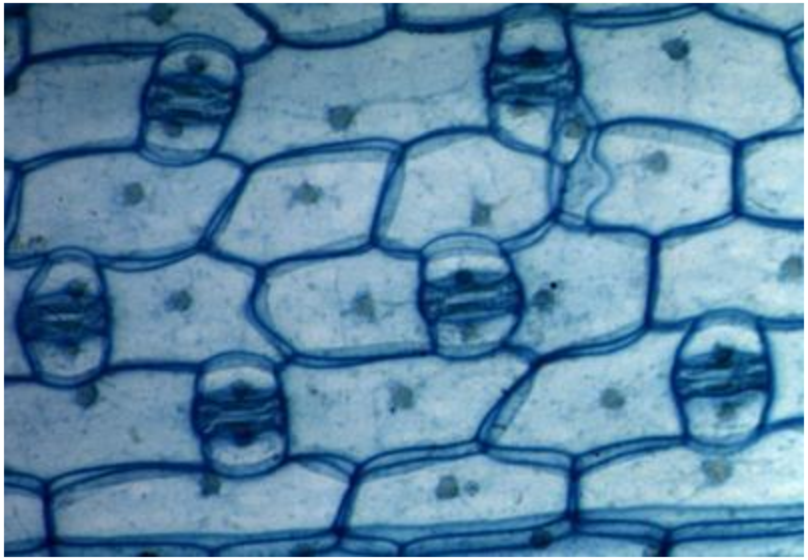


Primary Tissues of Leaves

- Epidermis/cuticle (protection; desiccation)
- *Stomata* (tiny pores for gas exchange and transpiration)/*guard cells*
- *Mesophyll*: ground tissue between upper and lower epidermis (parenchyma with chloroplasts);
  - palisade (most photosynthesis) and spongy (gas circulation)

STOMATA





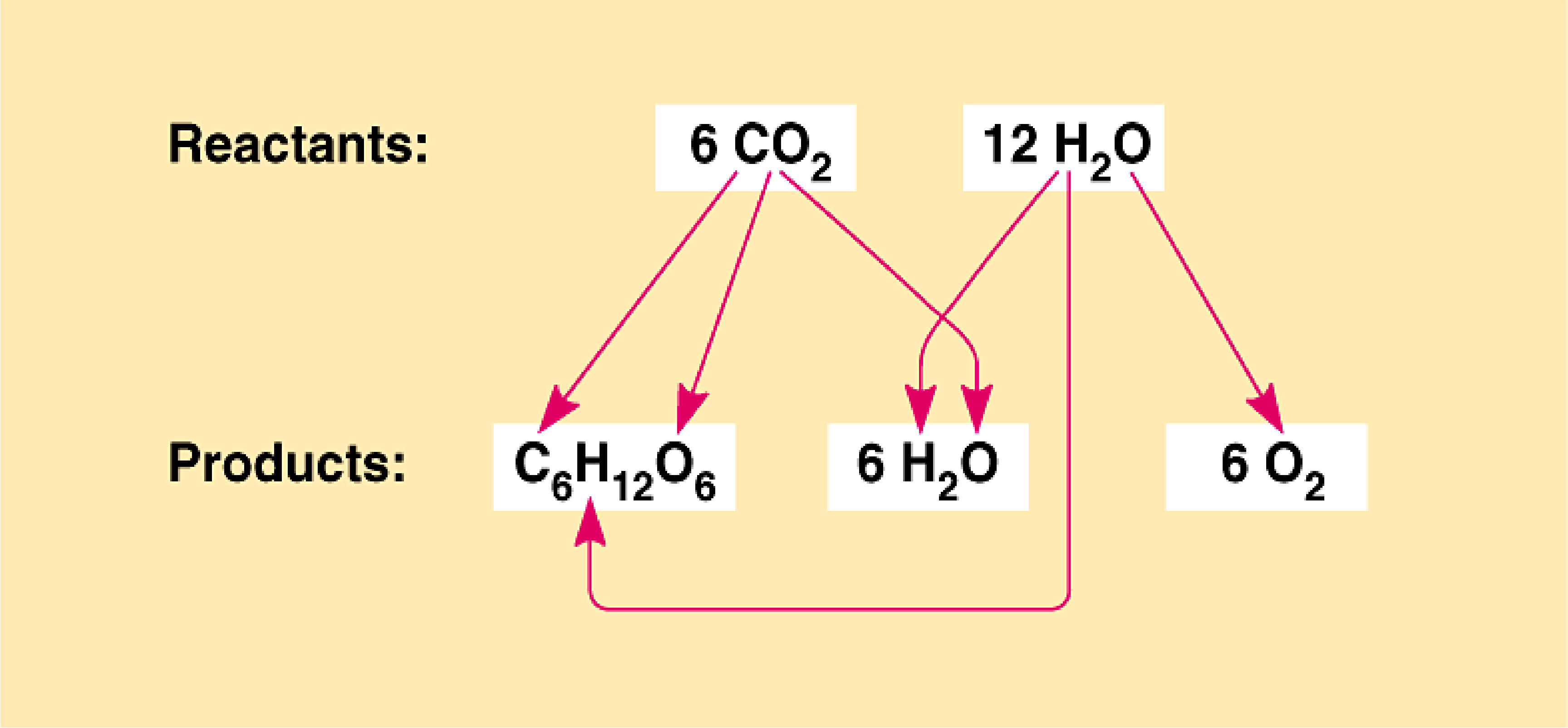
Overview

- Photosynthesis is the conversion of light energy into chemical bond energy

  $6\ CO_2 + 12\ H_20 \rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_20$

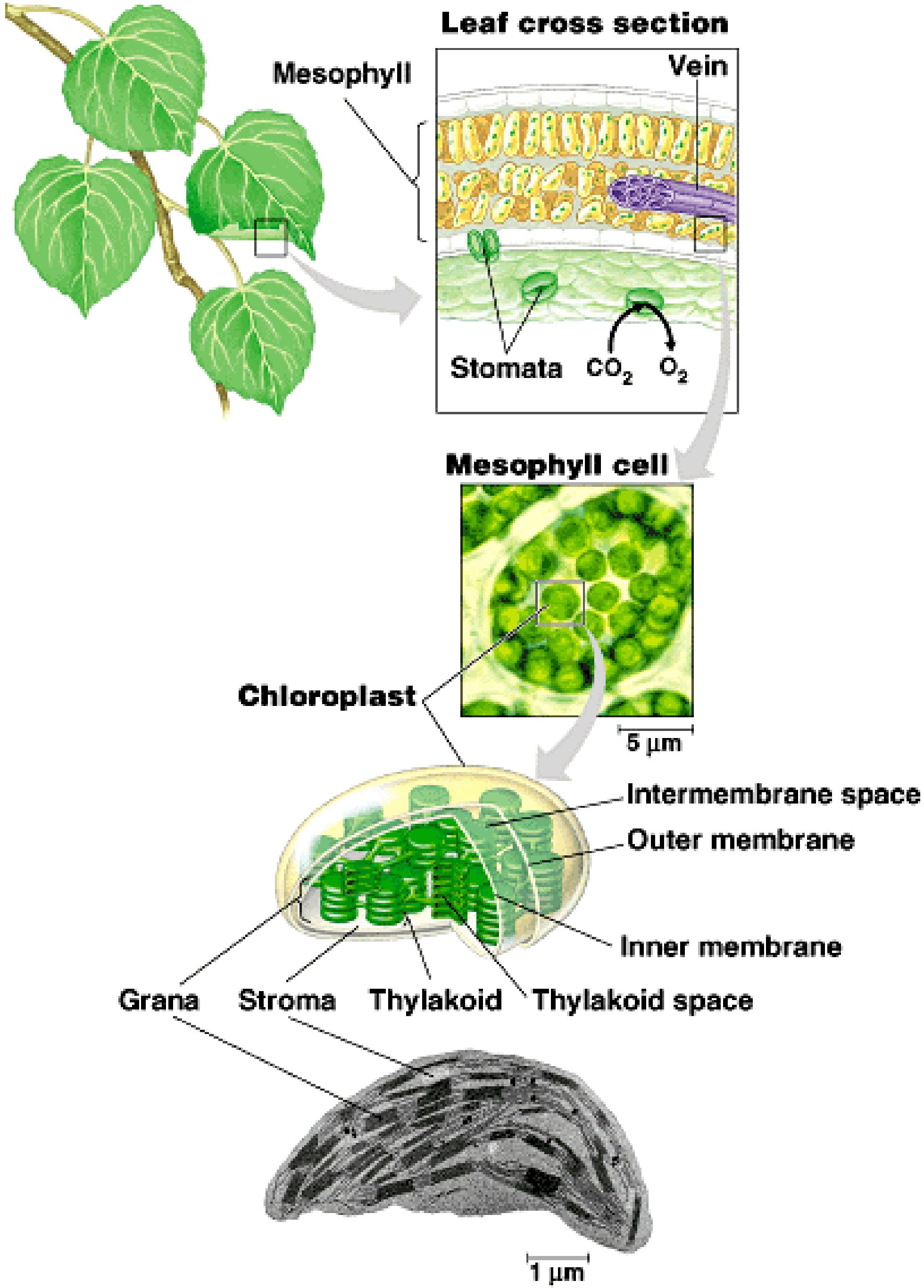
  - This is the reverse of cellular respiration; thus, photosynthesis & cellular respiration are coupled reactions.
  - It occurs in two stages:
    - Light Reactions – in the thylakoid space
    - Calvin Cycle – in the stroma

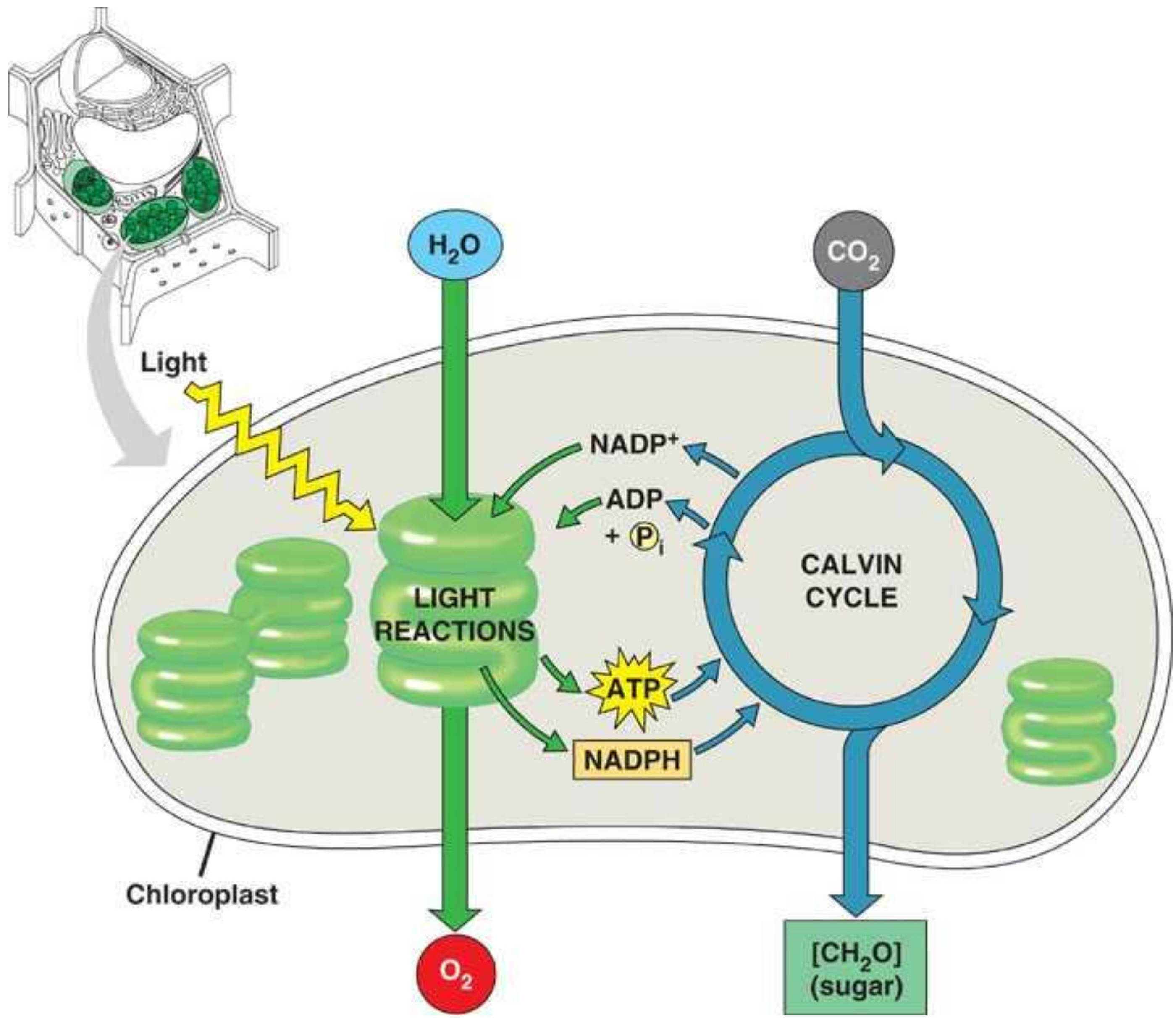
Tracking Atoms in Photosynthesis



Where does it occur?

- Chloroplasts – photosynthetic organelles
  - All green parts of a plant contain chloroplasts
  - Divided into 3 distinct compartments:
    - **Intermembrane space**: separates the inner and outer chloroplast membrane
    - **Thylakoid space**: consists of stacks of thylakoids which are arranged in stacks called grana; location of chlorophyll
      - Light reactions occur here
    - **Stroma**: viscous (thick) fluid outside the thylakoids
      - Calvin cycle occurs here

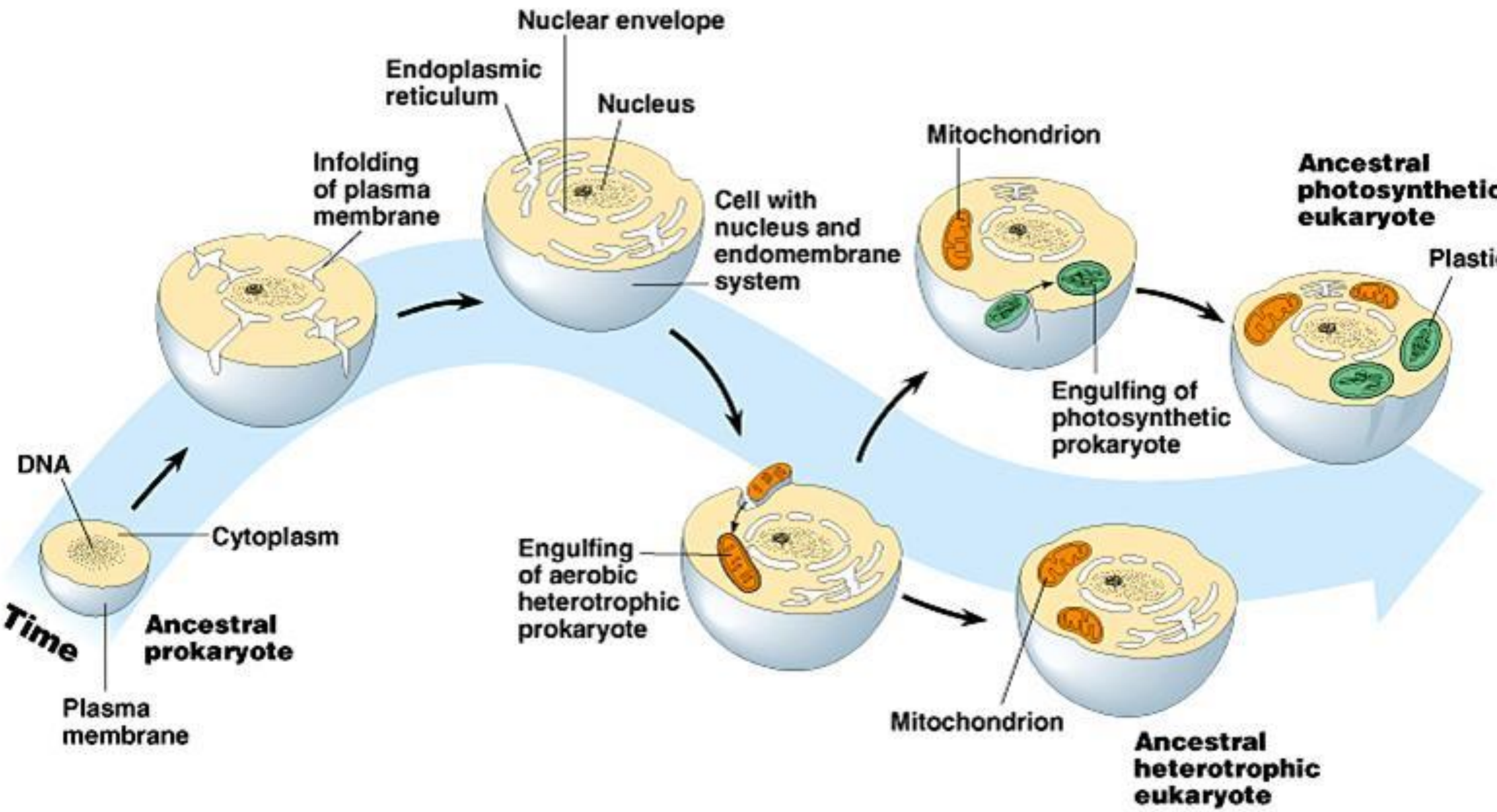

Leaf cross section
Mesophyll
Vein
Stomata
CO_2
O_2
Mesophyll cell
Chloroplast
5 µm
Intermembrane space
Outer membrane
Inner membrane
Grana
Stroma
Thylakoid
Thylakoid space
1 µm



Light
H_2O
CO_2
NADP+
ADP
+ Pi
LIGHT
REACTIONS
CALVIN
CYCLE
ATP
NADPH
Chloroplast
O_2
[CH_2O]
(sugar)

How did chloroplasts and mitochondria get into the plant cell?

- Endosymbiotic Theory
  - The arise of eukaryotic cells from prokaryotic cells
  - First, nucleus was formed from infolding of plasma membrane
  - Second, aerobic heterotrophic bacteria was engulfed by another bacteria
  - Third, some of the cells engulfed photosynthetic bacteria
- Cells may have begun as prey or parasites, but a mutually beneficial relationship resulted


Nuclear envelope
Endoplasmic reticulum
Nucleus
Infolding of plasma membrane
Cell with nucleus and endomembrane system
Mitochondrion
Ancestral photosynthetic eukaryote
Plastid
Engulfing of photosynthetic prokaryote
DNA
Cytoplasm
Engulfing of aerobic heterotrophic prokaryote
Time
Ancestral prokaryote
Plasma membrane
Mitochondrion
Ancestral heterotrophic eukaryote

Nature of Light

- Visible light's wavelength stretches from 380nm to 750nm.
- The visible range of light is the radiation that drives photosynthesis.
- Light consists of particles called PHOTONS which are fixed quantities of energy.

- What happens when chlorophyll & other pigments absorb photons?
  - When a molecule of a pigment (color) absorbs a photon, one of the molecules’ **electrons is elevated** to an orbital or energy level where it has **more potential energy**
    - Increase wavelength; decrease energy
    - Decrease wavelength; increase energy

Ground State vs Excited State Electrons

- **Ground State** – electron is in its normal orbital

- **Excited State** – an electron in its higher energy orbital; occurs after the absorption of a photon; very unstable.

Light Reactions

- Reactions that convert light energy to chemical bond energy in ATP and NADPH.
  - Occur in the thylakoid membranes of chloroplasts
  - Reduce (gain electrons) $NADP^+$ to NADPH
  - Give off O_2 as a by-product from the splitting of H_20
  - Generate ATP through photophosphorylation

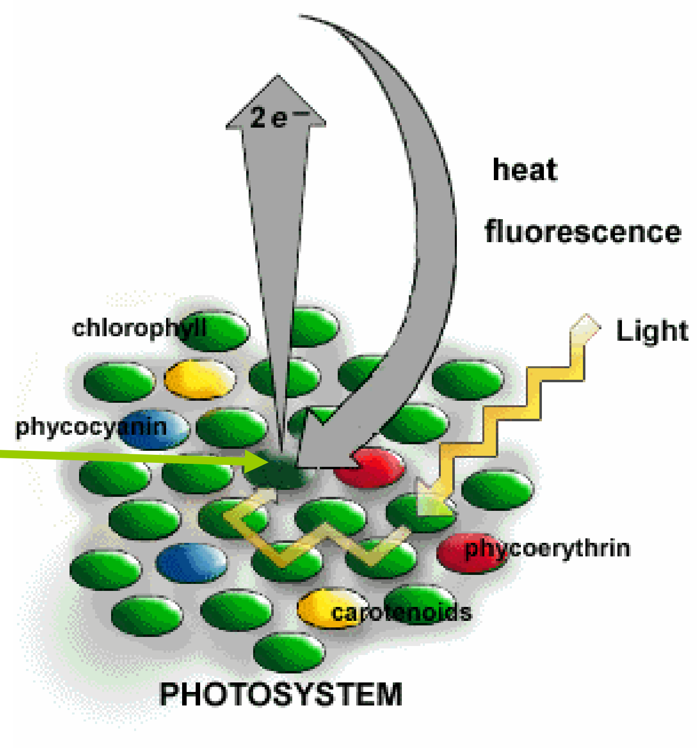
Photosystems

- Chlorophyll molecules are organized in the thylakoid membrane into photosystems
  - **Photosystem structure**:
    - **Reaction center** surrounded by light harvesting complexes
      - Reaction Center = protein complex that includes 2 chlorophyll a molecules and a primary electron acceptor
      - In chlorophyll, the acceptor molecule functions as a dam, preventing the flow of electrons to plunge immediately back to their ground state

–**Photosystem structure**:

- **Light harvesting complex** = chlorophyll a, chlorophyll b, & carotenoids bound to proteins
  - Acts as an antenna for the reaction center to absorb light

REACTION CENTER



Photosystems I & II

- Thylakoid membrane has two photosystems (II and I) – named in order of discovery, but PHOTOSYSTEM II functions first followed by Photosystem I

- **Photosystem II**:
  - Reaction center = P680 chlorophyll a (functions best at wavelengths of 680nm of light)
- **Photosystem I**:
  - Reaction center = P700 chlorophyll a (functions best at wavelengths of 700nm of light)

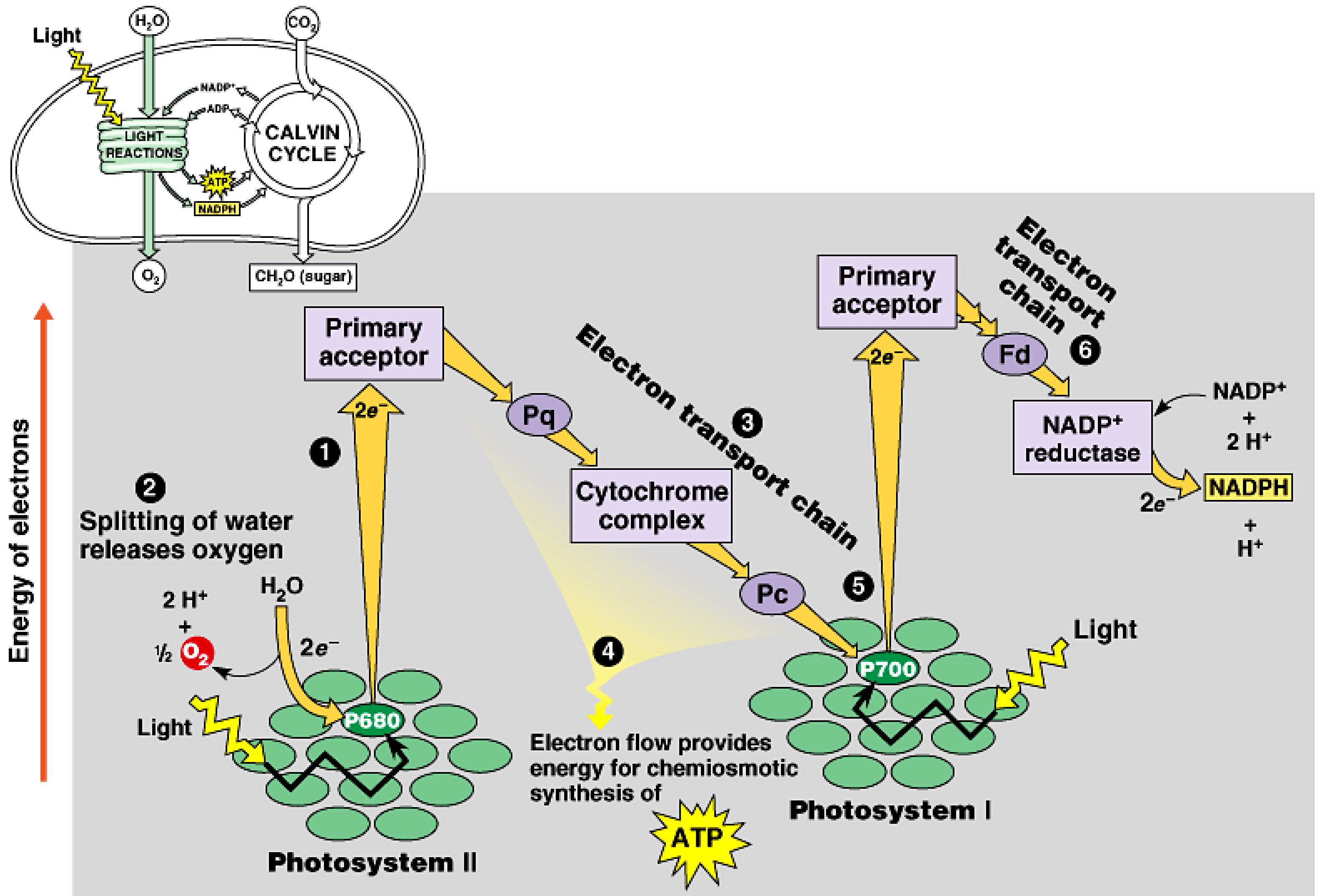
Photosystem II

- **<u>Non-cyclic electron flow</u>** – electrons pass continually from H_20 and chlorophyll to NADPH

- P680 absorbs light with a wavelength best of 680nm and excites electrons in the chlorophyll
- Passes the electrons to protein chain

Photosystem II

- P680 gains back the electrons it lost by splitting H_20 – this also creates O_2.
- As the excited electrons slide down the chain connecting photosystem II with photosystem I, the chain pumps H+ across the thylakoid membrane to the thylakoid space.
  - The build up of H+ can then drive ATP synthesis: Chemiosmosis


Light
H_2O
CO_2
NADP+
ADP
LIGHT REACTIONS
CALVIN CYCLE
ATP
NADPH
O_2
CH_2O (sugar)
Energy of electrons
Primary acceptor
2e−
1
2
Splitting of water releases oxygen
2 H+ + ½ O_2
H_2O
2e−
Light
P680
Photosystem II
Pq
Electron transport chain
3
Cytochrome complex
Pc
4
Electron flow provides energy for chemiosmotic synthesis of
ATP
5
Primary acceptor
2e−
P700
Light
Photosystem I
Electron transport chain
Fd
6
NADP+ + 2 H+
NADP+ reductase
2e−
NADPH
+ H+

Photosystem I

- P700 – absorbs light with a wavelength of 700nm
- Light energy excites electron in the chlorophyll, which is passed along the more of the protein chain
- Electrons from Photosystem II are used to replace the lost electron
- 2 electrons are used to make NADPH

Photosystem I

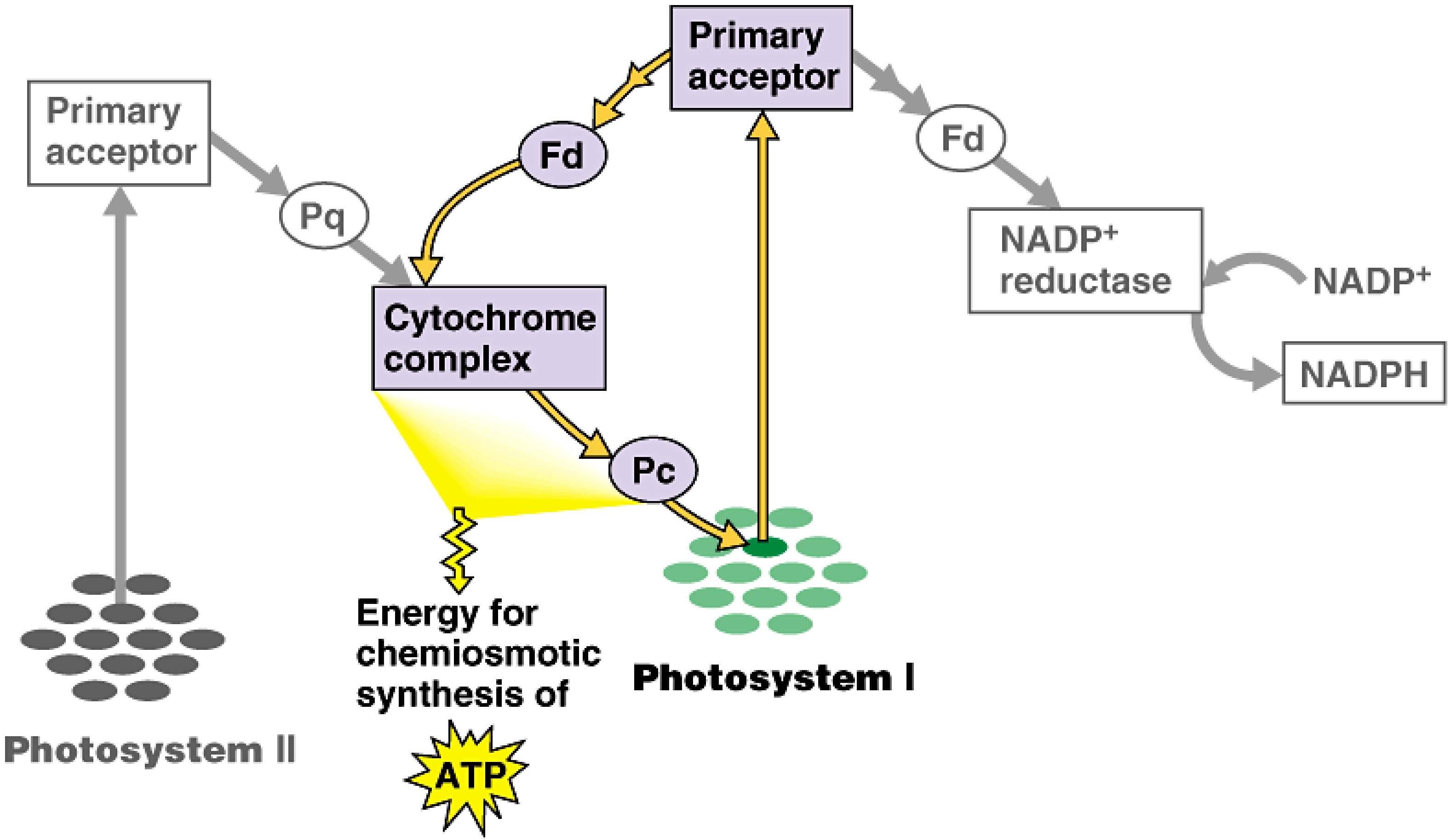
<u>**Cyclic electron flow**</u> – alternative pathway that just involves Photosystem I

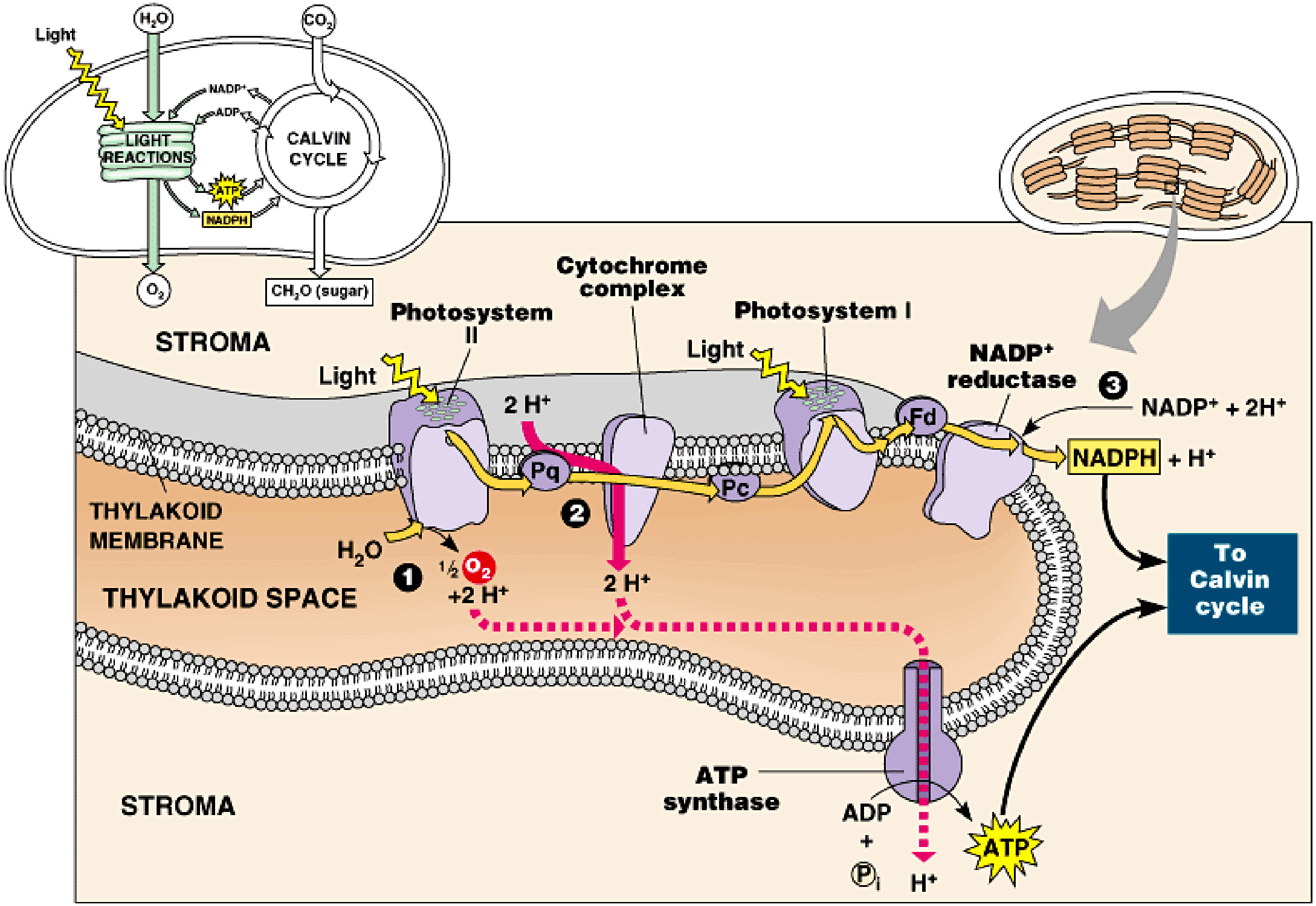
- Simpler pathway of electron flow than Photosystem II
- electrons cycle back to cytochrome complex (proteins in the chain) continues back into Photosystem I
- Only ATP is generated – NO NADPH or O_2 is harvested
- Only used when there is a build up of NADPH or more ATP is required for Calvin Cycle

Summary Light Reactions

- Noncyclic electron flow = captures electrons from water and transfers to NADP+
  - low potential energy [water] to high potential energy [NADPH]
- Light reactions produce O_2 from splitting H_2O
- Electron transport chain in the thylakoid membranes generate ATP
  - ATP is released into the stroma for the DARK REACTION [Calvin cycle]
- ATP & NADPH are used in the Calvin cycle to produce carbohydrates and release O_2 as a byproduct.

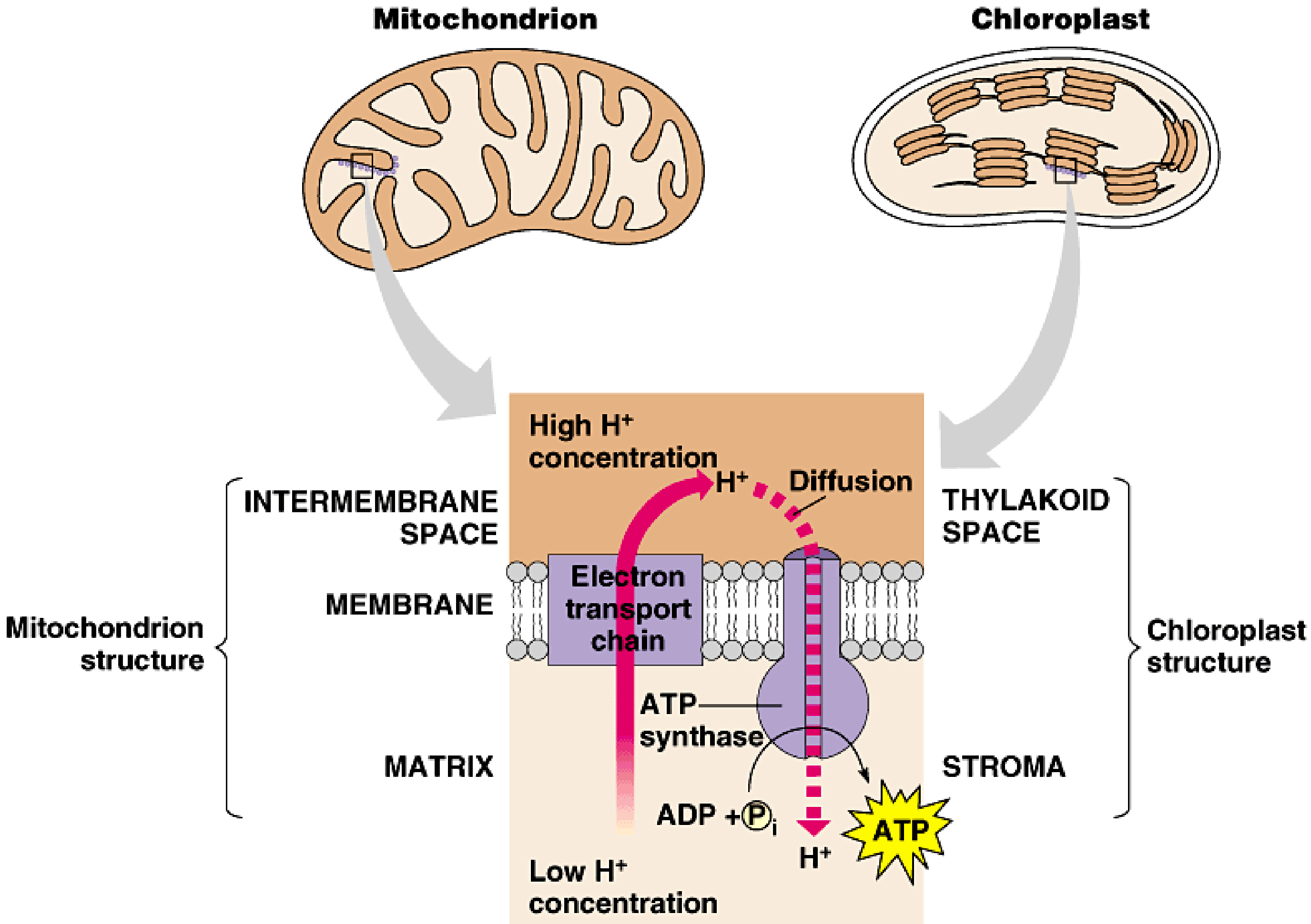
Cyclic electron flow





Chloroplasts and Mitochondria both generate ATP by chemiosmosis

Chemiosmosis – Mitochondria vs. Chloroplast



Calvin Cycle

- CO_2 is reduced to carbohydrates by a series of reactions in the Calvin cycle.
  - Reactions occur in the STROMA
  - Incorporate CO_2 into existing organic molecules by a process called carbon fixation and then is reduced to a carbohydrate.
  - Does NOT require light directly
  - NADPH provides the reducing power
  - ATP provides the chemical energy

Calvin Cycle (Dark Reaction)

- Calvin cycle uses ATP and NADPH produced in the light reactions to convert CO_2 to sugar
- ATP is the energy source
- NADPH is the reducing agent that adds high-energy electrons to form sugar G3P (glyceraldehyde 3-phosphate)

- 3 CO_2 enter the Calvin Cycle to generate one G3P molecule

- G3P is the raw material, produced by the Calvin cycle, that is used to synthesize glucose and other carbs

Calvin Cycle

- Anabolic process that uses energy to build carbs from smaller molecules.
- Carbon enters the cycle in the form of CO2 and leaves as sugar
- Carbohydrate actually produced is not glucose but a 3C sugar, glyceraldehyde-3-phosphate (G3P)

Phase 1 of Calvin Cycle: Carbon Fixation

- CO_2 is added to a 5C sugar, ribulose bisphosphate (RuBP).
  - Added by enzyme, Rubisco
- Produces a 6C sugar that immediately splits in half (2 3C sugars) due to instability: 3-Phosphoglycerate (PGA)

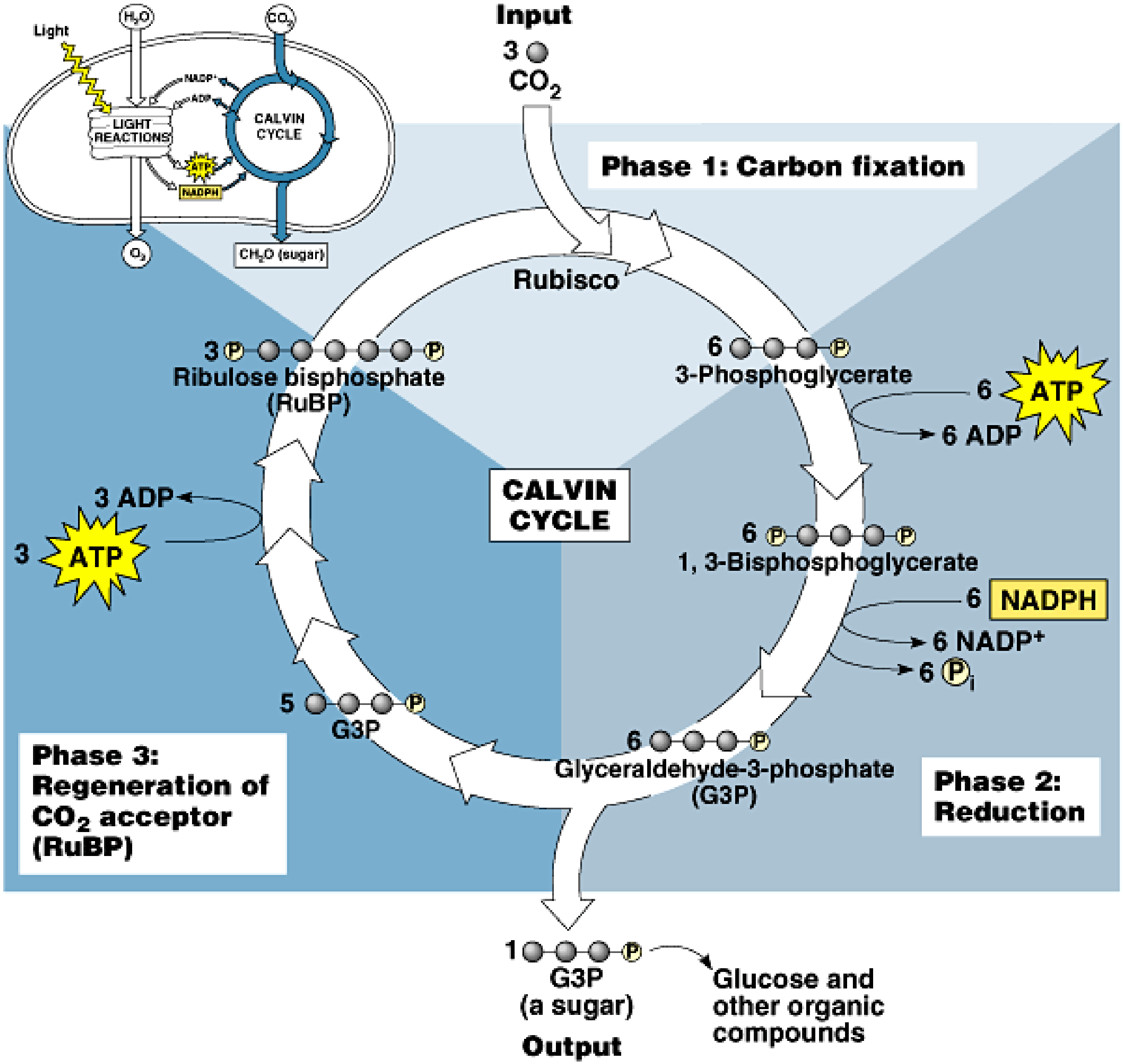
Phase 2 of Calvin Cycle : Reduction

- Phosphate added to make a different 3 carbon molecule

- NADPH donates electrons to produce G3P sugar molecule

Phase 3 of Calvin Cycle : Regeneration of the CO2 Acceptor (RuBP)

- 5 molecules of G3P are rearranged by the last steps of the Calvin Cycle
  - Forms 3 molecules of RuBP
- For the NET synthesis of ONE G3P molecule, the Calvin cycle uses the products of the light reactions:
  - 9 ATP molecules
  - 6 NADPH molecules


Light
H_2O
CO_2
$NADP^+$
ADP
LIGHT REACTIONS
CALVIN CYCLE
ATP
NADPH
O_2
CH_2O (sugar)
Input
3 CO_2
Rubisco
Phase 1: Carbon fixation
6 3-Phosphoglycerate
6 ATP
6 ADP
CALVIN CYCLE
6 1, 3-Bisphosphoglycerate
6 NADPH
6 $NADP^+$
6 P_i
6 Glyceraldehyde-3-phosphate (G3P)
Phase 2: Reduction
3 Ribulose bisphosphate (RuBP)
3 ADP
3 ATP
5 G3P
Phase 3: Regeneration of CO_2 acceptor (RuBP)
1 G3P (a sugar)
Output
Glucose and other organic compounds