Photosystems

Photosystem (fig 10.12) = rxn center surrounded by several light-harvesting complexes

Light-harvesting complex = pigment molecules bound to proteins (act as antenna for rxn center)

Rxn center = protein complex that includes 2 special chlorophyll a molecules + primary e- acceptor molecule

First step of light rxns: special chlorophyll a molecule transfers its excited e- to the primary e- acceptor

A Photosystem: A Reaction Center Associated with Light-Harvesting Complexes

- A photosystem
  - Is composed of a reaction center surrounded by a number of light-harvesting complexes

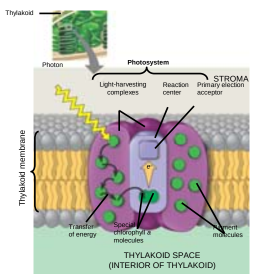


Figure 10.12

Light-harvesting Complexes and Reaction Centers

- The light-harvesting complexes consist of pigment molecules bound to particular protein
- They funnel the energy from photons of light to the reaction center
- When a reaction-center chlorophyll a molecule absorbs energy, one of its electrons gets bumped up to a primary electron acceptor

Photosystems

Two types of photosystems embedded in the thylakoid membranes of land plants (fig 10.13)

1. **Photosystem I** (**PS I**)
Rxn center chlorophyll a = P700
Cyclic and noncyclic e- flow

2. **Photosystem II** (**PS II**)
Rxn center chlorophyll a = P680
Noncyclic e- flow

Noncyclic e- flow (fig 10.13)
Uses PS II & PS I
Excited e- from PS II → goes through ETC → produces ATP
Excited e- from PS I → ETC → used to reduce NADP+
Electrons ultimately supplied from splitting water → releases O_2 and H^+
Cyclic e- flow (fig 10.15)
Uses only PS I
Only generates ATP
Excited e- from PS I cycle back from 1st ETC
No O_2 release & no NADPH made

Two Photosystems

- The thylakoid membrane
  - Is populated by two types of photosystems, I and II

Noncyclic Electron Flow – Involves both Photosystems

- Produces NADPH, ATP, and oxygen, and is the primary pathway of energy transformation in the light rxns.

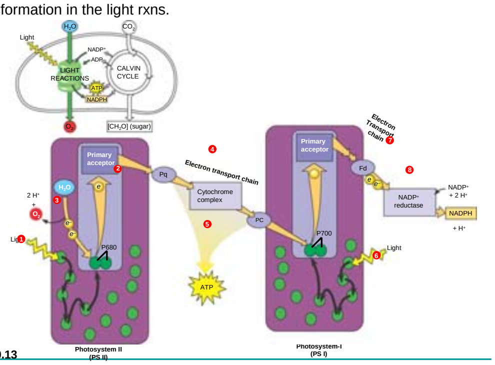


Figure 10.13

A mechanical analogy for the light reactions

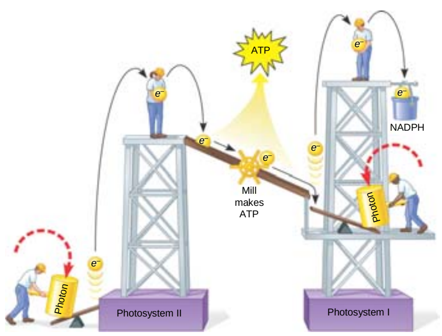


Figure 10.14

Cyclic Electron Flow

- Under certain conditions
  - Photoexcited electrons take an alternative path
  - Uses Photosystem I only

In cyclic electron flow

- In cyclic electron flow
  - Electrons cycle back to the first ETC
  - Only ATP is produced

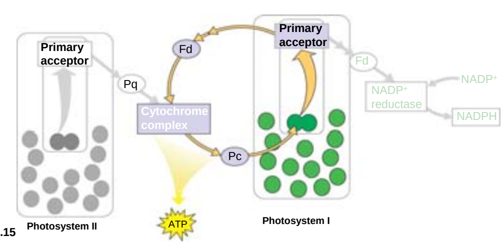


Figure 10.15

Light Reactions and Chemiosmosis

<u>The light reactions and chemiosmosis</u>: (fig 10.17)
As e- are brought down their E gradient through the ETCs embedded in the thylakoid membranes → that E is being used to pump H+ into the thylakoid space

ATP synthase is the only place H+ can flow along its concentration gradient → E from this flow is used to join ADP + Pi → ATP

NADPH is made by NADP$^+$ reductase

ATP and NADPH → used to power Calvin cycle

Light reactions and chemiosmosis: organization of the thylakoid membrane

As e- are brought down their E gradient through the ETCs embedded in the thylakoid membranes → that E is being used to pump H+ into the thylakoid space
ATP synthase is the only place H+ can flow along its concentration gradient → E from this flow is used to join ADP + Pi → ATP

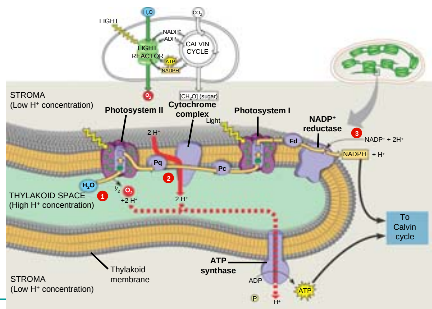


Figure 10.17

Light Reactions and Chemiosmosis

<u>Comparison of chemiosmosis in mitochondria & chloroplasts</u> (fig 10.16):

ATP generation basically the same (ETC + ATP synthase)

Mitochondria use high-E e- extracted from organic molecules (glucose)

Chloroplasts use light E to drive e- to top of the ETC

Comparison of Chemiosmosis in Chloroplasts and Mitochondria

- Chloroplasts and mitochondria
  - Generate ATP by the same basic mechanism: chemiosmosis
  - But use different sources of energy to accomplish this. Chloroplasts use light energy and mitochondria use the chemical energy in organic molecules.

The spatial organization of chemiosmosis

- Differs in chloroplasts and mitochondria

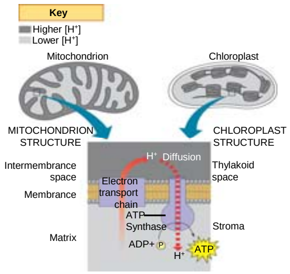


Figure 10.16

Chemiosmosis: Chloroplasts vs. Mitochondria

- In both organelles
  - Redox reactions of electron transport chains generate a H^+ gradient across a membrane
- ATP synthase
  - Uses this proton-motive force to make ATP

The Calvin Cycle

The Calvin cycle uses ATP + NADPH to convert $CO_2 \rightarrow$ sugar

Calvin cycle (fig 10.18) = anabolic process that **builds** carbohydrates from smaller molecules

Consumes E (ATP)

Uses NADPH as reducing agent for adding high E e- to make sugar

Phase 1: Carbon fixation

CO_2 incorporated by attaching to 5-C sugar (ribulose bisphosphate = **RuBP**)

Catalyzed by **Rubisco** (ribulose bisphosphate carboxylase/oxygenase) = most abundant protein on Earth!

Unstable 6-C intermediate $\rightarrow$ 2 molecules of 3-phosphoglycerate (3-C sugar)

Phase 2: Reduction

3-phosphoglycerate has phosphate added $\rightarrow$ NADPH reduces intermediate $\rightarrow$ G3P (glyceraldehyde-3-phosphate)

One G3P exits the cycle to be used by the plant cell

Other 5 recycled to regenerate RuBP

Phase 3: Regeneration of CO_2 acceptor (RuBP)

Requires ATP

Five G3P (3-C) $\rightarrow$ Three 5-C molecules of RuBP

Calvin cycle uses ATP & NADPH to convert CO_2 to sugar

- The Calvin cycle
  - Is similar to the citric acid cycle
  - Occurs in the stroma

The Calvin Cycle

Calvin cycle (fig 10.18) = anabolic process that **builds** carbohydrates from smaller molecules (CO_2 and H_2O

Consumes E (ATP) from the light reactions

Uses NADPH (from the light reactions) as the reducing agent for adding high energy e- to make sugar

The Calvin cycle

- The Calvin cycle

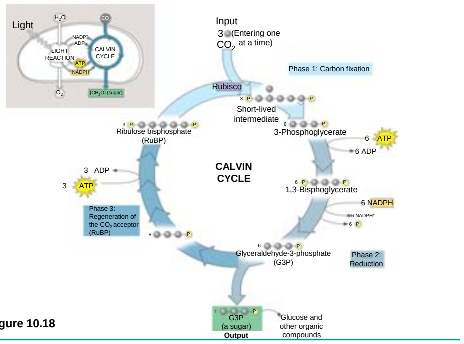


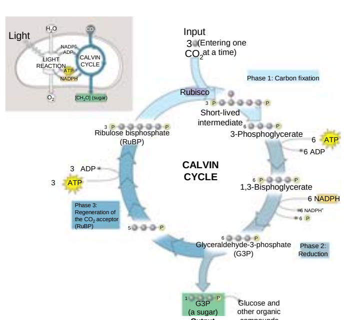
Figure 10.18

The Calvin cycle has three phases

- The Calvin cycle has three phases
  - Carbon fixation
  - Reduction
  - Regeneration of the CO_2 acceptor

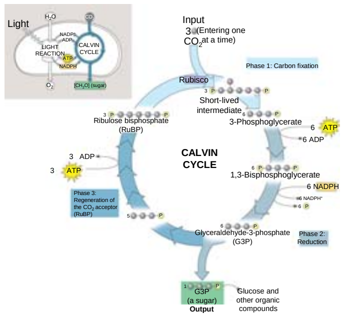
The Calvin cycle

- **Phase 1: Carbon fixation**
- CO_2 incorporated by attaching to 5-C sugar (ribulose bisphosphate = **RuBP**)
- Catalyzed by **Rubisco** (ribulose bisphosphate carboxylase/oxygenase) = most abundant protein on Earth!
- Unstable 6-C intermediate → 2 molecules of 3-phosphoglycerate (3-C sugar)



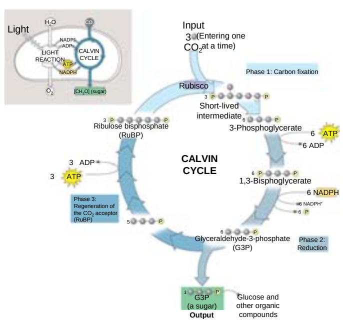
The Calvin cycle

- **Phase 2: Reduction**
- 3-phosphoglycerate has phosphate added → NADPH reduces intermediate → G3P (glyceraldehyde-3-phosphate)
- One G3P exits the cycle to be used by the plant cell
  - Other 5 recycled to regenerate RuBP



The Calvin cycle

- **Phase 3: Regeneration of CO_2 acceptor (RuBP)**
- Requires ATP
- Five G3P (3-C) → Three 5-C molecules of RuBP



Balancing gas exchange against water loss

Terrestrial plants have to balance gas exchange (CO_2 + O_2) w/ H_2O loss
Happens at the stomata on leaves

If a plant closes its stomata during hottest part of day → accumulation of O_2 & no CO_2 uptake

Photorespiration = process that uses O_2 instead of CO_2 → only generates 1/2 the amount of 3-phosphoglycerate → **decreases Ps output** by siphoning organic material from Calvin cycle (up to 50%)
Rubisco can act on both CO_2 & O_2 (not discriminate)

C3 plants
Most plants
Use only Calvin cycle to fix CO_2 in mesophyll
Limited by photorespiration

On hot, dry days, plants close their stomata

- Conserving water but limiting access to CO_2
- Causing oxygen to build up

Photorespiration: An Evolutionary Relic?

- In photorespiration
  - O_2 substitutes for CO_2 in the active site of the enzyme rubisco
  - The process consumes oxygen and releases CO_2
  - The photosynthetic rate is reduced

Adaptations to Hot, Arid Climates

- Alternative mechanisms of carbon fixation have evolved in hot, arid climates
  - C4 plants separate initial carbon fixation from the Calvin cycle in space
  - CAM plants separate initial carbon fixation from the Calvin cycle in time

Adaptations to Hot, Arid Climates

- **C4 plants** (fig 10.21a) - exhibit a **spatial separation** of C-fixation
- Preface Calvin cycle with alternate mode of C-fixation that forms a **4-C compound** (occurs in **mesophyll cells**) – Ex. Corn and sugarcane
- Associated w/ unique leaf anatomy (**Kranz anatomy**, fig 10.19)
- **PEP carboxylase** adds CO_2 to PEP (phosphoenolpyruvate) → 4-C oxaloacetate → converted to malate → transported to **bundle sheath cells** → broken down to CO_2 (Calvin cycle) + pyruvate (3-C goes back to mesophyll to regenerate PEP)
- PEP carboxylase has a much higher affinity for CO_2 than rubisco does, and no affinity for O_2
- **CAM plants** (fig 10.21b) Ex. Succulents, cacti, pineapples, etc.
- **Crassulacean Acid Metabolism** plants adapted to arid environments
  - **Temporal separation** of C-fixation: open stomata at night and close during day
- Take up CO_2 at night → oxaloacetate → malate → malic acid stored in vacuole during the day
- ATP + NADPH synthesized during day → malic acid transported out of vacuole → malate → CO_2 + pyruvate at night

Adaptations to Hot, Arid Climates

- **C4 plants** (fig 10.21a)
- **CAM plants** (fig 10.21b)
- These types of plants separate initial carbon fixation from the Calvin Cycle either in space or time.
- This allows them to keep their stomata partially closed during the day to minimize water loss.

C_4 Plants

- C_4 plants minimize the cost of photorespiration
  - By incorporating CO_2 into four carbon compounds in mesophyll cells
- These four carbon compounds
  - Are exported to bundle sheath cells, where they release CO_2 used in the Calvin cycle

C_4 leaf anatomy and the C_4 pathway

- Separates initial carbon fixation from the Calvin cycle in space

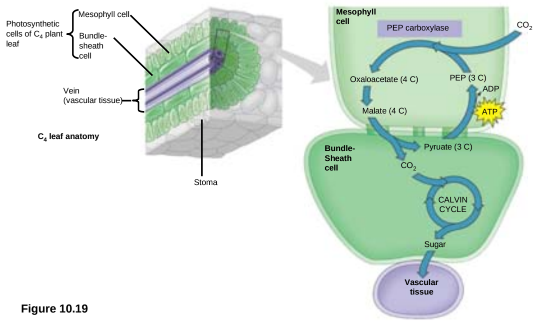


Figure 10.19

CAM Plants

- CAM plants
  - Open their stomata at night, incorporating CO_2 into organic acids
  - During the day, the stomata close
    - And the CO_2 is released from the organic acids for use in the Calvin cycle
- So they separate initial carbon fixation from the Calvin cycle in time.

CAM pathway is similar to the C_4 pathway

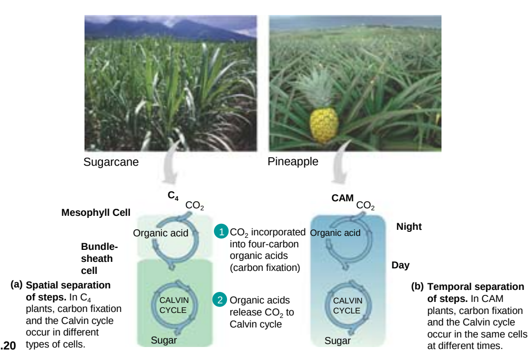


Figure 10.20

Importance of Photosynthesis

- About 50% of the organic material made by Ps is consumed as fuel for respiration in the plant body
- Not all plant cells make their own food → have to be supplied by Ps cells
- Two most important products we derive from plants come directly from Ps (what are they?)
- Fig 10.21 = nice overview of Ps

The Importance of Photosynthesis: *A Review*

- A review of photosynthesis

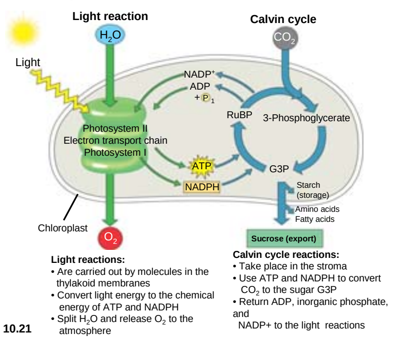


Figure 10.21

Two most important products of photosynthesis

- Organic compounds produced by photosynthesis
  - Provide the energy and building material for ecosystems
- Oxygen produced by photosynthesis
  - provides an aerobic environment that allows for cellular respiration