Summary of Chapter 18

1. Photosynthesis is carried out at **chloroplasts** in the plant cells.
2. Photosynthesis occurs in two distinct phases: **light reaction** and **dark reaction**.

3. Light reaction.
   - Light is absorbed by antenna **chlorophyll** (Chl) and accessory **pigments** in **light-harvesting complexes (LHCs)**.
   - Chl is derived from the protoporphyrin IX, and contains Mg^{2+}.
   - The absorbed light energy (exciton) is transferred to the adjacent Chl or other pigment until it is trapped by **photosynthetic reaction center**.
   - One mole of light (6.02 × 10^{23} photons = 1 einstein) with λ= 700 nm has 171 kJ/einstein:
     \[ E = \frac{Nhc}{\lambda} = \frac{(6 \times 10^{19})(6.6 \times 10^{-34} \text{ J} \cdot \text{s}^{-1})(3 \times 10^{8} \text{ m} \cdot \text{s}^{-1})}{700 \times 10^{-9} \text{ m}} = 171 \text{ kJ/einstein} \]
   - Bacteria photosynthesis is one center process whereas photosynthesis in plants and algae is two center process.
      1. **Photosystem II (PSII)** generates a weak reductant and strong oxidant to oxidize H_{2}O.
         \[ 2 \text{H}_{2}\text{O} + \text{light (4 photons)} \rightarrow \text{O}_2 + 4e^- + 4\text{H}^+ \quad \Delta E^{\circ} = -0.815 \text{ V} \]
      2. **Photosystem I (PSI)** generates a strong reductant to reduce NADP^{+} and weak oxidant.
         \[ 2\text{NADP}^+ + 4e^- + 2\text{H}^+ + \text{light (4 photons)} \rightarrow 2\text{NADPH} \quad \Delta E^{\circ} = -0.320 \text{ V} \]
   - The **Cyt b_{6f} complex** located between PSII and PSI pumps 8H^{+} from stroma to thylakoid when 4e^- pass through the complex.
   - The electrons are carried by the mobile electron carriers, **plastoquinol (PQ)** and **plastocyanin (PC)**, between the complexes.
   - Electron pathway:
      1. The H_{2}O is oxidized by **O_{2}-evolving complex (OEC)** in PSII, which contains 4Mn cluster.
      - The released electrons from H_{2}O go to **substance Z**.
      2. The **PSII reaction center P680** is activated to form a weak reductant.
      3. The mobile electron carrier PQ transports electron to Cyt b_{6f} complex.
      - 8H^{+} are transported from stroma to thylakoid.
      4. The electrons are carried by another mobile carrier PC to the **PSI reaction center P700**.
      5. The P700 is activated to form a strong reductant.
      6. The electrons are transferred to **ferredoxin (Fd)** and to **FAD-containing Fd-NADP^{+} reductase** which reduces the NADP^{+} to NADPH.
      - For the cyclic pathway, the electrons are back to Cyt b_{6f} complex, where 4H^{+} is pumped to thylakoid.
      - PSI and PSII occupy different parts of the thylakoid membrane in order to allow chloroplasts to respond to different types of light (full and shady sun).
      - The reduced PQH_{2} activates PK which phosphorylates LHC, i.e., LHC → P-LHC.
      - The P-LHC moves to the PSI and funnels the photons into the PSI.
      - The oxidized PQ dephosphorylates LHC which tends to funnel the photons into the PSII.
      - Photophosphorylation is used only ΔpH across the membrane to synthesize ATP from ADP.
4. Dark reaction
   - It takes place in stroma, and is called **Calvin cycle**.
   - CO_{2} molecules are fixed to produce carbohydrates (starch and sucrose) by using the ATP and NADPH produced by the light reaction.
- The CO₂ fixation is carried out by using pentose phosphate enzymes and other enzymes.
- The most important other enzyme is **ribulose-bisphosphate carboxylase (Rubisco)**.
- Rubisco catalyzes the RuBP + CO₂ → 2(3PG) reaction.
- Major route of Calvin cycle is to produce the nucleotide-glucose (XDP-G):
  \[
  \text{Ru5P} \xrightarrow{\text{ATP}} \text{RuBP} \xrightarrow{\text{CO}_2} 2(3\text{PG}) \xrightarrow{\text{ATP}} 2(\text{BPG}) \xrightarrow{\text{NADPH}} 2(\text{GAP})
  \]
  \[
  \text{GAP} \xrightarrow{\text{DHAP}} \text{FBP} \xrightarrow{\text{GBP}} \text{G1P} \xrightarrow{\text{XDP - G}}
  \]
  where XDP = UDP, ADP, GDP or CDP.
- Products from XDP-G are:
  Starch ← XDP-G → F6P → sucrose-P → sucrose
- Calvin cycle can be two stage reactions
  1. Stage-1: Production of GAP
     \[
     3\text{RuBP} + 9\text{ATP} + 3\text{CO}_2 + 6\text{NADPH} + 6\text{H}^+ \rightarrow 6\text{GAP} + 6\text{NADP}^+ + 9\text{ADP} + 6\text{P}_i
     \]
  2. Stage-2: Recovery
     \[
     5\text{GAP} \rightarrow 3\text{Ru5P} + 2\text{P}_i
     \]
  - Overall reaction:
    \[
    3\text{CO}_2 + 9\text{ATP} + 6\text{NADPH} + 6\text{H}^+ \rightarrow \text{GAP} + 6\text{NADP}^+ + 9\text{ADP} + 8\text{P}_i
    \]
- The dark reaction is controlled by Rubisco activity. Rubisco is activated by:
  - High pH, high [Mg²⁺], high [NADPH] --- these conditions are met in day.
  - Rubisco is inactivated by CA1P which is synthesized only in night.
- Second regulatory system is the two phosphatase activities (FBPase and SBPase) in recovery stage. These phosphatase activities are increased by high pH, high [Mg²⁺] and high [NADPH].
  - Actually: \( h\nu \rightarrow \text{PSI}_{\text{red}} \rightarrow \text{Fd}_{\text{red}} \rightarrow (\text{Ferredoxin-thioredoxin reductase})_{\text{red}} \rightarrow (\text{Thioredoxin})_{\text{red}} \rightarrow (\text{Bisphosphatase})_{\text{red}} = \text{active} \rightarrow \text{increase gluconeogenesis and reduce glycolysis.}

5. Photorespiration
   - Rubisco also catalyzes RuBP + O₂ → 3PG + 2-phosphoglycolate (C₂).
   - Overall photorespiration is:
     \[
     2\text{RuBP} + \text{O}_2 \rightarrow 2(3\text{PG}) + \text{Ser} + \text{CO}_2
     \]
     \[
     \text{Ser} + 3\text{PG} + \text{NADPH} + \text{ATP} \rightarrow \text{RuBP} + \text{CO}_2 + \text{NADP}^+ + \text{ADP}
     \]
     \[
     \text{RuBP} + \text{NADPH} + \text{ATP} \rightarrow 3\text{PG} + 2\text{CO}_2 + \text{NADP}^+ + \text{ADP}
     \]
   - Thus, photorespiration is wasteful process.

6. C₄ cycle plants avoid photorespiration.
   - The surface of leaves are covered by mesophyll cells (no Rubisco), where CO₂ in air is stored as malate by PEP + CO₂ → Oxaloacetate → Malate --- Four carbon acids.
   - The malate is transported in the bundle-sheath cell where it is reoxidized to pyruvate and CO₂.
   - CO₂ enters the Calvin cycle.

7. CAM plants avoid photorespiration by closing stomata during day to prevent loss of H₂O. Thus, O₂ cannot enter in cells in daytime.
   - At night (Rubisco activity is very low), CO₂ is stored in malate, and at daytime (Rubisco activity is high), CO₂ is regenerated from the stored malate, and enters into the Calvin cycle.