Chapter 23 – The Calvin Cycle (CO₂ Fixation)

Problems: 3-12,16,18-20,22,23

The “Dark” Reactions

• Reductive conversion of CO₂ into carbohydrates

• Process is powered by ATP and NADPH (formed during the light reactions of photosynthesis)

The CO₂ fixation pathway has several names:
• The reductive pentose phosphate (RPP) pathway.
• The C₃ pathway.
• The photosynthetic carbon reduction cycle.
• The Calvin cycle.

CO₂ enters the plant through pores on the leaf surface called stomata.
23.1 The Calvin Cycle Synthesizes Hexoses from Carbon Dioxide and Water

The Calvin Cycle

Figure 23.1
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Stage 1, Fixation: Ribulose 1,5-Bisphosphate Carboxylase-Oxygenase (Rubisco)

- Gaseous CO$_2$ and the 5-carbon sugar ribulose 1,5-bisphosphate form two molecules of 3-phosphoglycerate
- Reaction is metabolically irreversible ($\Delta G^0' = -51.9$ kJ/mole)
- Rubisco makes up about 50% of the soluble protein in plant leaves, and is one of the most abundant enzymes in nature
Regulation of the Rubisco Reaction

- Rubisco cycles between an active form (in the light) and an inactive form (in the dark)
- Activation requires light, CO$_2$, Mg$^{2+}$ and correct stromal pH
- At night 2-carboxyarabinitol 1-phosphate (synthesized in plants) inhibits Rubisco
**Stage 2, Reduction**: Hexose Phosphates Are Made from Phosphoglycerate

These hexose phosphates are interconvertable. Also, glyceraldehyde-3-phosphate can be transported to cytol and converted to Fru-6-P and Glc-1-P via gluconeogenesis. These, in turn, can be used for sucrose or starch synthesis.

1,3-*bis*phosphoglycerate dehydrogenase (NADPH and not NADH)

3-phosphoglycerate kinase
Stage 3, Regeneration: Production of Ribulose bisphosphate from glyceraldehyde-3-phosphate.

\[
\text{Fru-6-P} + 2\text{GAP} + \text{DHAP} + 3\text{ATP} \rightarrow 3\text{Rib-1,5-bisP} + 3\text{ADP}
\]
Calvin Cycle Summary

Figure 23.5
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Chloroplasts → Cytoplasm

Triose phosphates (from chloroplasts) → Fructose 6-phosphate + UDP-glucose

Sucrose 6-phosphate synthase

Sucrose 6-phosphate → UDP + Pi

Sucrose (transported from leaves to roots)
23.2 Regulation of the Calvin Cycle

1. Stromal Environment: Increases In Mg$^{2+}$, NADPH, Fd$_{\text{red}}$, and a decrease in H$^+$

2. Activation of RUBISCO by light: addition of CO$_2$ to lysine (201), which is favored by alkaline pH and increased Mg$^{2+}$

3. Regulation of enzyme activities via thioredoxin.

Couples Calvin cycle to light rxns.
### Table 23.1 Enzymes regulated by thioredoxin

<table>
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<th>Enzyme</th>
<th>Pathway</th>
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<td>Rubisco</td>
<td>Carbon fixation in the Calvin cycle</td>
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<tr>
<td>Fructose 1,6-bisphosphatase</td>
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<td>Phenylalanine ammonia lyase</td>
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<tr>
<td>NADP⁺-malate dehydrogenase</td>
<td>C₄ pathway</td>
</tr>
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</table>
The “Wasteful” Oxygenase Reaction of Rubisco

No CO₂ fixation (O₂ utilization).
Uses ATP and NADPH without hexose production.

Photorespiration
4. Regulation of “Oxygenase” Activity by the C₄ Pathway.
5. Regulation of Oxygenase Reaction in Crassulacean acid metabolism (CAM)