5.12E: Regulation of the Calvin Cycle

LEARNING OBJECTIVES

• Outline the three major phases of the Calvin cycle: carbon fixation, reduction, and regeneration of ribulose

The Calvin cycle is a process utilized to ensure carbon dioxide fixation. In this process, carbon dioxide and water are converted into organic compounds that are necessary for metabolic and cellular processes. There are various organisms that utilize the Calvin cycle for production of organic compounds including cyanobacteria and purple and green bacteria. The Calvin cycle requires various enzymes to ensure proper regulation occurs and can be divided into three major phases:

1. carbon fixation,
2. reduction, and
3. regeneration of ribulose.

Each of these phases are tightly regulated and require unique and specific enzymes.
During the first phase of the Calvin cycle, carbon fixation occurs. The carbon dioxide is combined with ribulose 1,5-bisphosphate to form two 3-phosphoglycerate molecules (3-PG). The enzyme that catalyzes this specific reaction is ribulose bisphosphate carboxylase (RuBisCO). RuBisCO is identified as the most abundant enzyme on earth, to date. RuBisCO is the first enzyme utilized in the process of carbon fixation and its enzymatic activity is highly regulated. RuBisCO is only active during the day as its substrate, ribulose 1,5-bisphosphate, is not generated in the dark. RuBisCO enzymatic activity is regulated by numerous factors including: ions, RuBisCO activase, ATP /ADP and reduction/oxidation states, phosphate and carbon dioxide. The various factors influencing RuBisCO activity directly affect phase 1 of the Calvin cycle.

During the second phase of the Calvin cycle, reduction occurs. The 3-PG molecules synthesized in phase 1 are reduced to glyceraldehyde-3-phosphate (G3P). This reducing process is mediated by both ATP and NADPH. One of the two G3P molecules formed are further converted to dihydroxyacetone phosphate (DHAP) and the enzyme aldolase is used to combine G3P and DHAP to form fructose-1,6-bisphosphate. The enzyme aldolase is typically characterized as a glycolytic enzyme with the ability to split fructose 1,6-bisphosphate into DHAP and G3P. However, in this specific phase of the Calvin cycle, it is used in reverse. Therefore, aldolase is said to regulate a reverse reaction in the Calvin cycle. Additionally, aldolase can be utilized to promote a reverse reaction in gluconeogenesis as well. The fructose-1,6-bisphosphate formed in phase 2 is then converted into fructose-6-phosphate.

During the third phase of the Calvin cycle, regeneration of RuBisCO occurs. This specific phase involves a series of reactions in which there are a variety of enzymes required to ensure proper regulation. This phase is characterized by the conversion of G3P, which was produced in earlier phase, back to ribulose 1,5-bisphosphate. This process requires ATP and specific enzymes. The enzymes involved in this process include: triose phosphate isomerase, aldolase, fructose-1,6-bisphosphatase, transketolase, sedoheptulase-1,7-bisphosphatase, phosphopentose isomerase, phosphopentose epimerase, and phosphoribulokinase. The following is a brief summary of each enzyme and its role in the regeneration of ribulose 1,5-bisphosphate in the order it appears in this specific phase.
1. Triose phosphate isomerase: converts all G3P molecules into DHAP
2. Aldolase and fructose-1,6-bisphosphatase: converts G3P and DHAP into fructose 6-phosphate
3. Transketolase: removes two carbon molecules in fructose 6-phosphate to produce erythrose 4-phosphate (E4P); the two removed carbons are added to G3P to produce xylulose-5-phosphate (Xu5P)
4. Aldolase: converts E4P and a DHAP to sedoheptulose-1,7-bisphosphate
5. Sedoheptulase-1,7-bisphosphatase: cleaves the sedoheptulose-1,7-bisphosphate into sedoheptulase-7-phosphate (S7P)
6. Transketolase: removes two carbons from S7P and two carbons are transferred to one of the G3P molecules producing ribose-5-phosphate (R5P) and another Xu5P
7. Phosphophentose isomerase: converts the R5P into ribulose-5-phosphate (Ru5P)
8. Phosphophentose epimerase: converts the Xu5P into Ru5P
9. Phosphoribulokinase: phosphorylates Ru5P into ribulose-1,5-bisphosphate

After this final enzyme performs this conversion, the Calvin cycle is considered complete. The regulation of the Calvin cycle requires many key enzymes to ensure proper carbon fixation.

**Key Points**

- In this process, carbon dioxide and water are converted into organic compounds that are necessary for metabolic and cellular processes.
- The three phases of the Calvin cycle, fixation, reduction, and regeneration require specific enzymes to ensure proper regulation.
- The last phase of the Calvin cycle, regeneration, is considered the most complex and regulated phase of the cycle.

**Key Terms**

- **calvin cycle**: A series of biochemical reactions that take place in the stroma of chloroplasts in photosynthetic organisms.
- **gluconeogenesis**: A metabolic process which glucose is formed from non-carbohydrate precursors.
- **ribulose**: A ketopentose whose phosphate derivatives participate in photosynthesis.