dioxide, for example when the stomata are closed on hot days, rubisco will fix oxygen to RuBP, a process called **photorespiration** (Figure 7.24). The process of photorespiration wastes the energy carriers that were produced in the light-dependent reaction and does not lead to the production of glucose. When photorespiration happens, the plant cannot generate sugar, which it must have to carry out aerobic cellular respiration.

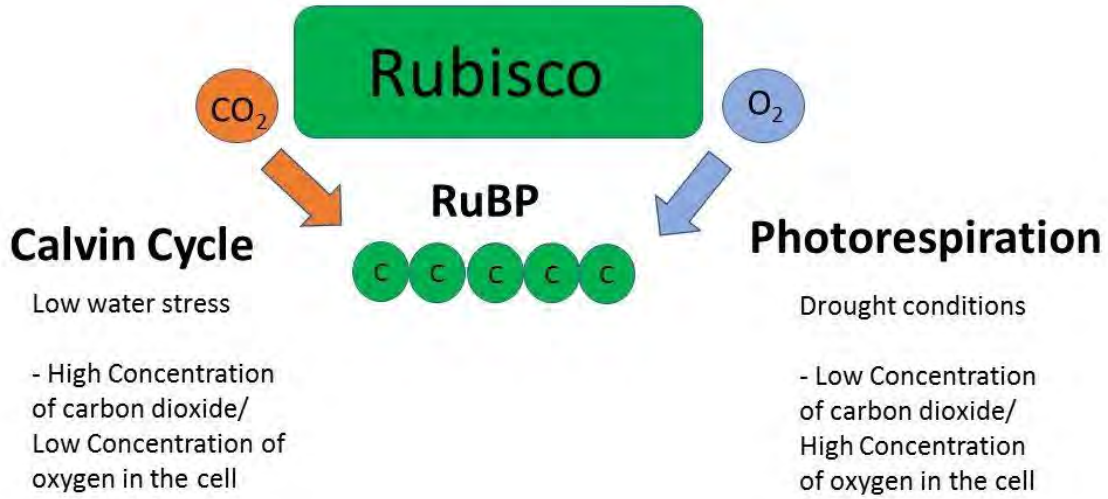

Figure 7.24 shows the difference between rubisco in the Calvin cycle and photorespiration. (credit: Elizabeth O'Grady)

Drought-adapted plants have evolved in such a way that they are able to reduce the impact of photorespiration. C4 plants, such as corn and sugar cane, can photosynthesize even when CO_2 is in short supply. When it is extremely hot and dry, plants are forced to close most or all of their stomata to prevent water loss. With their stomata closed, gas exchange is extremely limited and O_2 builds up. By using special enzymes and carrying out the Calvin cycle reactions in mesophyll cells called bundle sheath cells, photosynthesis can continue. They are called C4 plants because carbon dioxide must first be fixed into a four-carbon molecule, oxaloacetate, before it can be used to produce glucose.

CAM (Crassulacean Acid Metabolism) plants such as cacti (Figure 7.25), pineapple, and Spanish moss, open their stomata at night to exchange gas. By doing so, the plant can preserve water. Carbon dioxide can be stored in the central vacuoles until the daytime when the light dependent reactions can occur and produce the energy carriers needed to fix carbon dioxide during the Calvin cycle.

Both C4 and CAM plants have different adaptations that allow them to avoid photorespiration and carry out photosynthesis under water stress.

Figure 7.25 Cactus is an example of a CAM plant. (credit: Piotr Wojtkowski / Concepts of Biology OpenStax)

Photosynthesis in Prokaryotes

The two parts of photosynthesis, the light-dependent reactions and the Calvin cycle, have been described as they take place in chloroplasts. However, prokaryotes, such as cyanobacteria, lack membrane-bound organelles. Prokaryotic photosynthetic autotrophic organisms have infoldings of the plasma membrane for chlorophyll attachment and photosynthesis (Figure 7.26). It is here that prokaryotes, like cyanobacteria, can carry out photosynthesis.

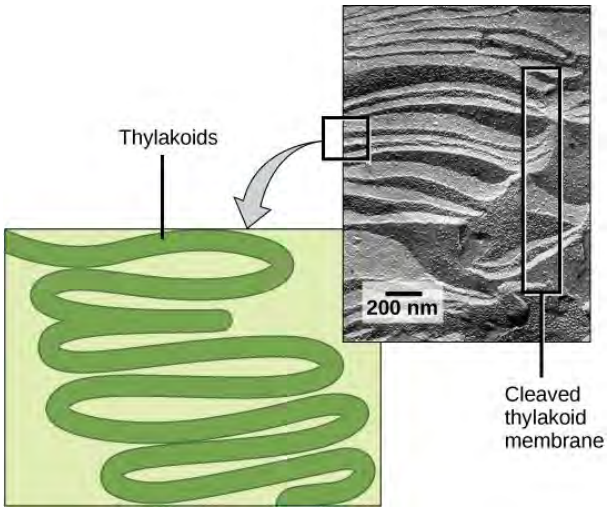

Figure 7.26 A photosynthetic prokaryote has folded regions of the plasma membrane that function like thylakoids. (credit: scale-bar data from Matt Russell / Concepts of Biology OpenStax)

Check your knowledge

Name the location of the light-dependent reactions in prokaryotes. Where is it in eukaryotes?

What are the inputs of the Calvin cycle?

Answer: In prokaryotes, the light-dependent reaction components are found in folds along the plasma membrane. In eukaryotes, they are on the thylakoid membranes in the chloroplast.
The Calvin cycle needs 18 ATP and the electrons carried by 12 NADPH from the light dependent reactions to fix the 6 CO2 into 2 G3P.

Section Summary

Using the energy carriers formed in the first stage of photosynthesis, the Calvin cycle reactions fix CO_2 from the environment to build carbohydrates. An enzyme, rubisco, catalyzes the carbon fixation reaction, by combining CO_2 with RuBP. The resulting six-carbon compound is broken down into two three-carbon compounds, and the energy in ATP and NADPH is used to convert these molecules into G3P. One of the three-carbon molecules of G3P leaves the cycle to become a part of a carbohydrate molecule. The remaining G3P molecules stay in the cycle to regenerate the RuBP, which is ready to react with more CO_2. Three carbon dioxide molecules are required to make each G3P. Two G3P molecules can be combined to form one glucose molecule. C4 and CAM plants have evolved variations of photosynthesis that allow them to survive in dry, hot climates, which reduces photorespiration.

Exercises

1. Where in plant cells does the Calvin cycle take place?
    a. thylakoid membrane
    b. thylakoid space
    c. stroma
    d. granum
2. Which statement correctly describes carbon fixation?
    a. the conversion of inorganic CO_2 to an organic compound
    b. the use of RUBISCO to form 3-PGA
    c. the production of carbohydrate molecules from G3P
    d. the formation of RuBP from G3P molecules
    e. the use of ATP and NADPH to reduce CO_2
3. What is the molecule that leaves the Calvin cycle to be converted into glucose?
    a. ADP
    b. G3P
    c. RuBP
    d. 3-PGA
4. Which part of the Calvin cycle would be affected if a cell could not produce the enzyme rubisco?

Answers

1. (c)
2. (a)
3. (b)
4. None of the cycle could take place because rubisco is essential in fixing carbon dioxide. Specifically, rubisco catalyzes the reaction between carbon dioxide and RuBP at the start of the cycle.

Glossary

Calvin cycle: the reactions of photosynthesis that use the energy stored by the light-dependent reactions to form glucose and other carbohydrate molecules

photorespiration: when oxygen is in a higher concentration than carbon dioxide, rubisco will fix oxygen to RuBP