THE THREE STAGES OF THE CALVIN CYCLE

To understand clearly the Calvin cycle, the discussion is divided into sections to focus on each of the three stages, namely, (1) carbon fixation, (2) reduction, and (3) regeneration of ribulose 1, 5-bisphosphate (fig. 7.6).

Carbon Fixation

In the carbon fixation stage, carbon dioxide enters the Calvin cycle by reacting with a 5-carbon sugar *ribulose 1, 5-bisphosphate* (RuBP). This reaction is catalyzed by the enzyme *rubisco* (stands for *ribulose bisphosphate carboxylase/oxygenase*), which is considered the most abundant protein on the surface of the earth. A very unstable 6-carbon intermediate is formed and immediately splits into two molecules of *3-phosphoglycerate* (3-PGA). Because 3-PGA is a 3-carbon molecule, the Calvin cycle is also referred to as the C_3 *cycle.* Thus, in this step, inorganic carbon (CO_2) is incorporated in an organic form. In the process, three CO_2 fuse with three RuBP to give a total of 18 carbons. At this point, six molecules of 3-PGA are formed.

Reduction

During reduction stage, each molecule of 3-PGA gets phosphorylated to form *1, 3-bisphosphoglycerate (1, 3-bisPGA)* with the phosphate group coming from ATP. Because six molecules of 3-PGA were formed from the carbon fixation step, six ATPs will be used in this phosphorylation step. With the reducing power of NADPH, 1,3-bisPGA is converted to *glyceraldehyde-3-phosphate* (G3P), also referred to as

3-phosphoglyceraldehyde or PGAL. Thus, this step requires six molecules of NADPH to reduce six molecules of 1, 3-bisPGA into six molecules of G3P. Therefore, the immediate sugar produced by the whole photosynthetic reactions is G3P, not glucose.

Regeneration of RuBP

In this stage of regeneration of RuBP, only one out of every six G3P molecules is used to synthesize glucose, sucrose, starch, and other organic molecules. The remaining five are used in a series of reactions catalyzed by enzymes to produce three molecules of *ribulose-5-phosphate.* Each ribulose-5-phosphate is then phosphorylated using ATP to regenerate the RuBP that accepts CO_2 during the carbon fixation step. Thus, it takes three ATPs to regenerate RuBP.

To summarize, for every G3P synthesized, the Calvin cycle consumes nine ATP molecules (six ATPs during carbon fixation and reduction and three ATPs during regeneration of RuBP) and six NADPH molecules.

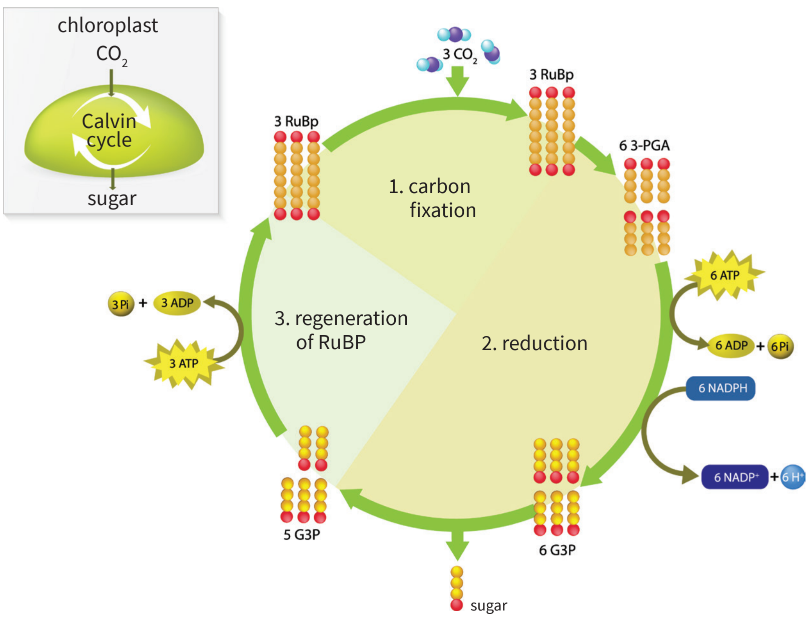

Fig. 7.6 In the Calvin cycle, carbon dioxide is first fixed to form 3-PGA, G3P is formed in a reduction step, and RuBP is regenerated. In every round of the cycle, inorganic carbon is fixed and becomes part of a sugar, an organic compound.

DID YOU KNOW?

The Calvin cycle used to be called the "dark reactions."

This was to distinguish the Calvin cycle, the second phase of photosynthesis, from the first phase or the light-dependent phase. Although the Calvin cycle does not directly involve light, it is misleading to say that the process is totally light-independent. It still needs light indirectly because for the Calvin cycle to proceed, it relies on the two products of the light reactions, ATP and NADPH. More so, many enzymes of this cycle, including rubisco, are activated by light. Thus, the Calvin cycle is a more appropriate term. It is named after one of its discoverers, American biochemist Melvin Calvin (1911–1997), who discovered the process along with two other American scientists, Andrew Benson (1917–2015) and James Alan Bassham (1922–2012).

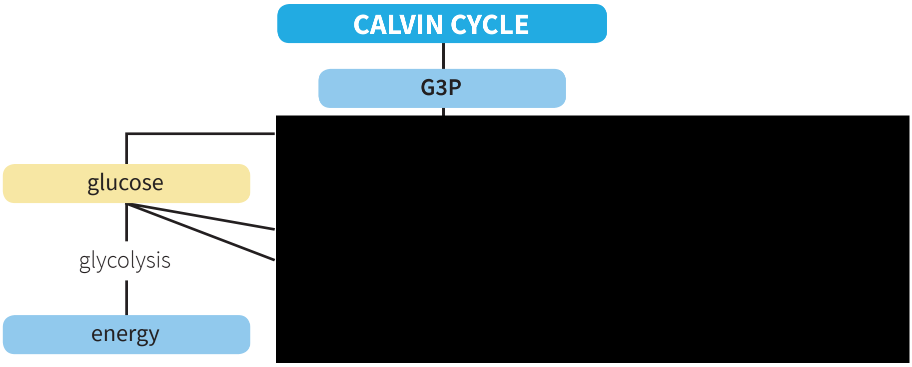

Fig. 7.7 The G3P produced by the Calvin cycle is used in various metabolic processes in the cell.

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What happens next to the triose sugars? These sugars enter various metabolic pathways, either in the chloroplast stroma where they were produced or in the cytosol where they were first transported before being acted upon.

In the chloroplast stroma, G3P is used to form *glucose-1-phosphate*, which is then used to synthesize starch, the major storage sugar of photosynthesizing cells and organisms. On the other hand, some triose phosphates are transported to the cytosol to be used to synthesize other molecules like fatty acids and amino acids. The glucose formed from G3P may enter *glycolysis*, a process that breaks up glucose to provide energy for the cell. It may also serve as starting material for the synthesis of sucrose, the major transport sugar in most plants, and of more complex carbohydrates like cellulose that constitute the cell walls of plants.