

PHOTOSYNTHESIS

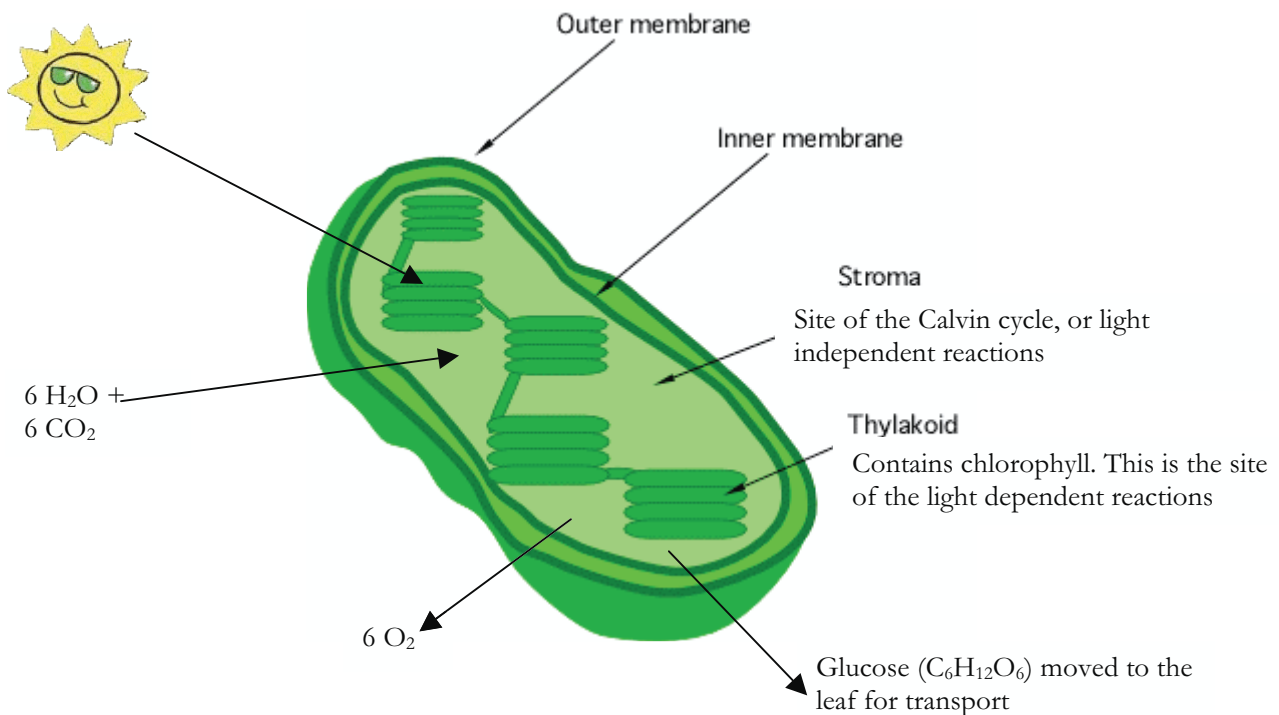
(How do the light dependent and light independent reactions provide food for a plant?)

Why?

How important are plants to life on Earth? Could life as we know it continue if there were no plants? Read on the find out why plants are truly the cornerstone of life.

Model 1:

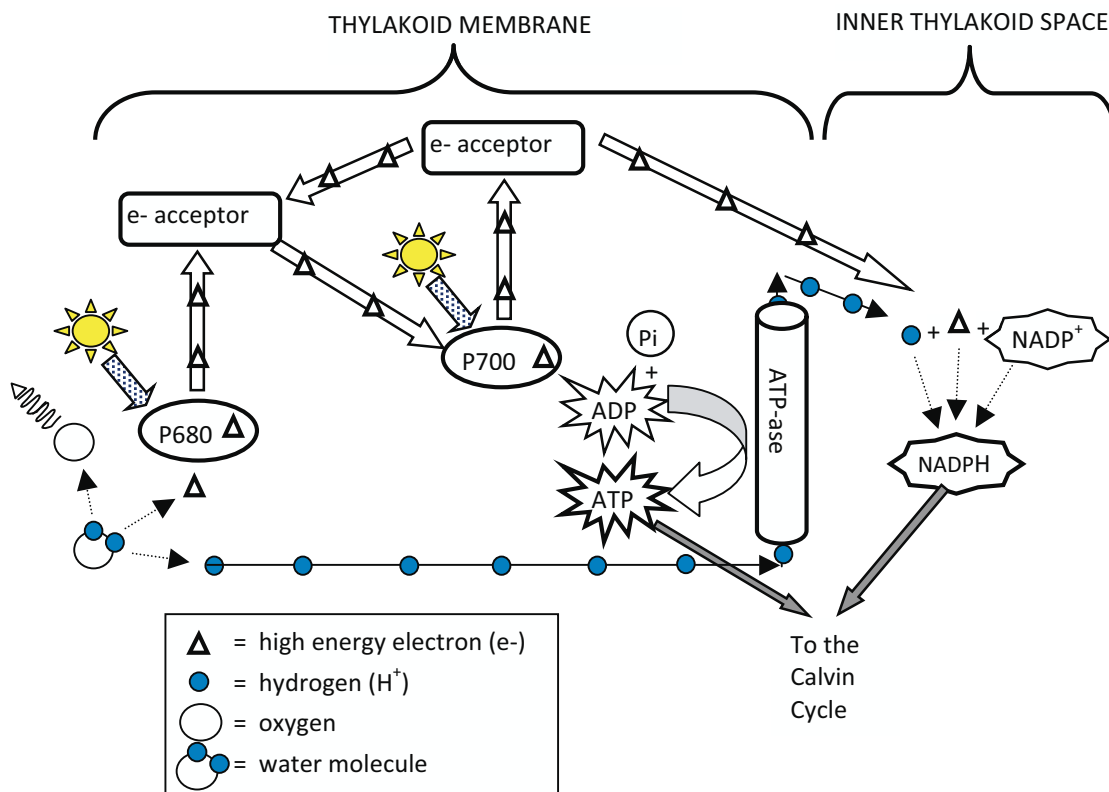
An Overview of Photosynthesis and Chloroplast Structure



1. Which part of the chloroplast contains chlorophyll?
2. Where does the CO₂ go?
3. Where is the energy from the sunlight used?
4. Name this process that uses the energy from the sunlight.

5. Could this process take place in the dark? Use complete sentences to justify your answer.
6. Where does the Calvin cycle take place?
7. What is another name for the Calvin cycle?
8. Is light necessary for this cycle to occur? Use complete sentences to justify your answer.
9. What essential biological molecules does photosynthesis produce?
10. Why is it necessary to have six CO₂ entering the chloroplast?

Model 2: The Light Dependent Reactions of Photosynthesis

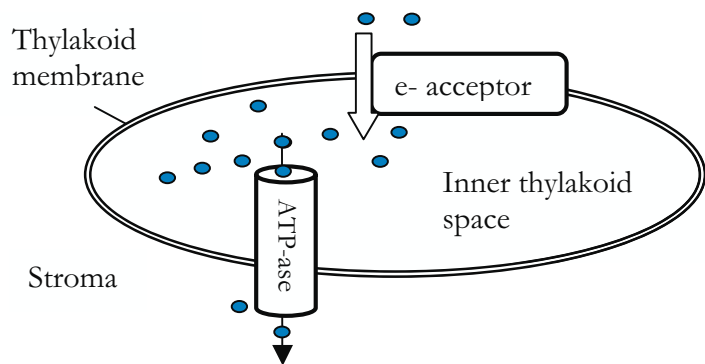


11. Is CO_2 involved in the light dependent reactions?
12. What has happened to the water in the diagram, and what three things are produced?
13. What pigment absorbs the light energy and how is it represented in this model?
14. What is the source of the electrons (e^-) that enter P680?
15. What molecule ultimately takes up the electrons that leave P680 and P700?
16. Where do the ATP and NADPH go?



Model 3: Close-up of the Thylakoid Membrane

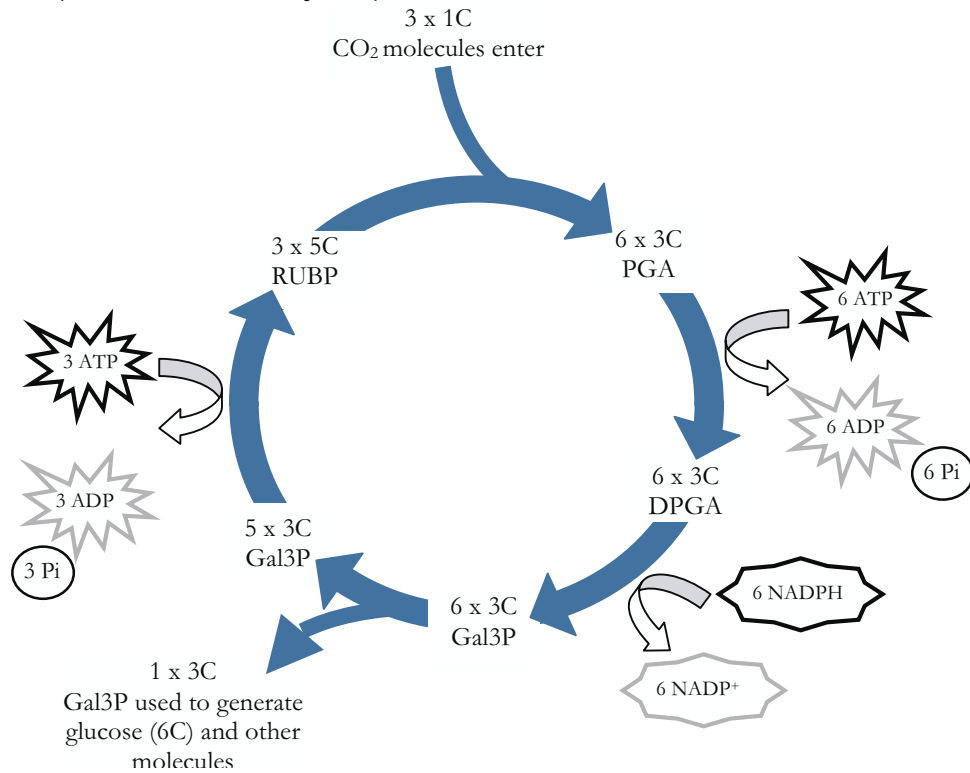
The electron transport chain is formed by a series of electron acceptor molecules in the thylakoid membrane. The movement of electrons through the transport chain provides energy to pump H^+ across the thylakoid membrane against the H^+ concentration gradient.



17. Why is energy needed to pump H^+ across the thylakoid membrane?
18. Why do the H^+ leak back into the stroma?
19. Through which molecule in the membrane does this leaking process occur and what type of biological molecule is this?
20. What molecule is produced as a result of the H^+ leaking back through the membrane?





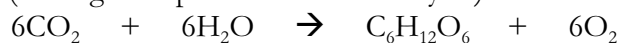
Model 4: The Light Independent Reaction of Photosynthesis (The Calvin Cycle)



21. How many CO₂ molecules enter the Calvin cycle?
22. What is the first molecule produced after the introduction of CO₂ and how many of these molecules are made?
23. How many carbon atoms does this molecule contain?
24. How many total carbon atoms are there at this point in the cycle?
25. What is the source of the rest of the carbon atoms (those that aren't from CO₂)?
26. What molecule supplies the energy for the reaction that converts PGA to DPGA and by what process was this molecule generated? (Consider all four of the models when answering this question.)

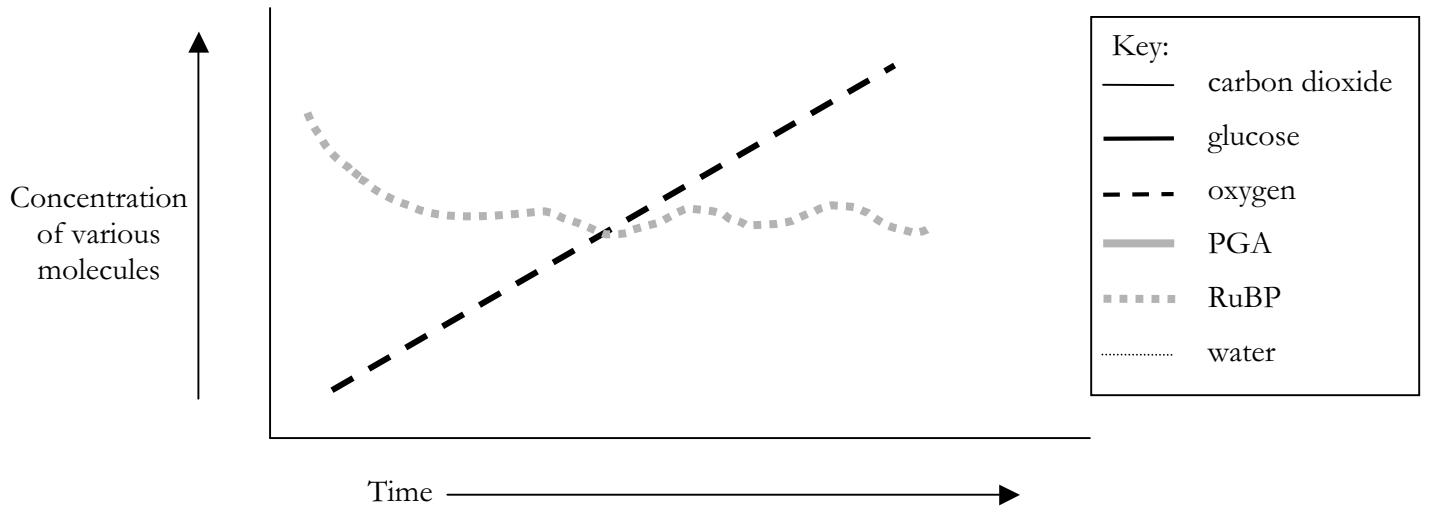


27. Where does the ADP go after the ATP is used in the Calvin cycle?
28. What molecule contributes to the conversion of DPGA to Gal3P and by which process was this molecule generated?
29. Where does the NADP⁺ go after the NADPH is used in the Calvin cycle?
30. Explain in detail, using complete sentences, how the two reactions (light dependent and light independent) depend on each other. 
31. What happens to the six molecules of Gal3P? Be specific and use complete sentences.
32. What molecule supplies the energy for the reaction that converts Gal3P to RuBP and by which process was this molecule generated?
33. How many carbon atoms are needed to create a single molecule of glucose?
34. How many turns of the Calvin Cycle are required to produce one molecule of glucose? 
35. How many molecules of NADPH and ATP are needed to produce one molecule of glucose?
36. Under each molecule in the equation below, indicate whether it is used or produced and in which reaction (the Light Dependent or Calvin Cycle) that occurs.



Extension Questions

37. When algae are undergoing photosynthesis, the concentration of various molecules changes within the cells. Graph the concentrations of glucose, carbon dioxide, water, and PGA during a period of active photosynthesis. The concentrations of oxygen, and RUBP have been graphed for you as examples. In this graphical representation, other cellular activities involving these molecules can be ignored.



38. In complete sentences, explain the reasoning behind your completed graph.
39. Photosynthesis is typically represented by a simple equation (see Model 1 or question 36). Using the information from this activity explain why this equation is a vastly oversimplified representation of the actual process.

Teacher Guide & Answer Key

Learning Objectives:

After completing the activity, the students should be able to:

1. Understand the separation of the light dependent and light independent reactions in terms of what is used & produced by each reaction.
2. Explain how some of the products of the light dependent reaction are essential for the light independent reaction, and vice versa.
3. Trace the path of CO_2 through the Calvin cycle to see that six molecules of carbon dioxide are used in two turns of the cycle to produce one molecule of glucose and to regenerate the molecules of RuBP.

Prerequisites:

The students will have previously learned the basics of photosynthesis, including the balanced equation. They should know that photosynthesis requires light and chlorophyll. Thus, Model 1 is meant to be a reminder of what they have learned in the past as well as an overview of chloroplast structure and function.

Evaluation Questions:

1. To produce one glucose molecule the Calvin cycle turns
 - a. Once
 - b. Twice
 - c. Three times
 - d. Six times
2. What products are produced during the light dependent reaction? *ATP, NADPH, and oxygen*
3. What molecules must be regenerated within the Calvin cycle to keep the cycle turning? *RuBP*

Target Audience:

This activity could be used in a high level honors/AP class

Materials:

None required



Stop Sign Suggestion:

At the stop sign prior to Model 4, be sure students understand how ATP and NADPH are formed during the light dependent reactions, and that water has been broken down and oxygen released. Highlight that glucose has not yet been produced, nor has carbon dioxide been used. If time is an issue, and students cannot complete the activity in a 45 minute period, this would be a good break-point. Start the next session by having students reiterate what has been used and produced in the light dependent reactions and what has yet to be used or produced.

Answer Key

1. Which part of the chloroplast contains chlorophyll? *Thylakoid*
2. Where does the CO₂ go? *Stroma*
3. Where is the energy from the sunlight used? *In the thylakoid*
4. Name this process that uses the energy from the sunlight. *Light dependent reaction*
5. Could this process take place in the dark? Use complete sentences to justify your answer.
No, it could not take place in the dark, because it must use light energy.
6. Where does the Calvin cycle take place? *In the stroma*
7. What is another name for the Calvin cycle? *Light Independent reaction*
8. Is light necessary for this cycle to occur? Use complete sentences to justify your answer.
No because it uses the energy made in the light dependent reaction so does not need sunlight; or it is called the "light independent reaction," so it does not need sunlight.
9. What essential biological molecule does photosynthesis produce? *Glucose (and oxygen)*
10. Why is it necessary to have six CO₂ entering the chloroplast? *Because 6C are needed to make one glucose*
11. Is CO₂ involved in the light dependent reactions? *No*
12. What has happened to the water in the diagram, and what three things are produced?
The water has split to produce H⁺ ions, oxygen, and electrons
13. What pigment absorbs the light energy and how is it represented in this model?
Chlorophyll; P680 & P700
14. What is the source of the electrons (e⁻) that enter P680? *Water that was split*
15. What molecule ultimately takes up the electrons that leave P680 and P700? *NADP⁺*
16. Where do the ATP and the NADPH go? *To the Calvin cycle (Light independent cycle).*
17. Why is energy needed to pump H⁺ across the thylakoid membrane? *Because it is going against a concentration gradient, therefore requiring active transport.*



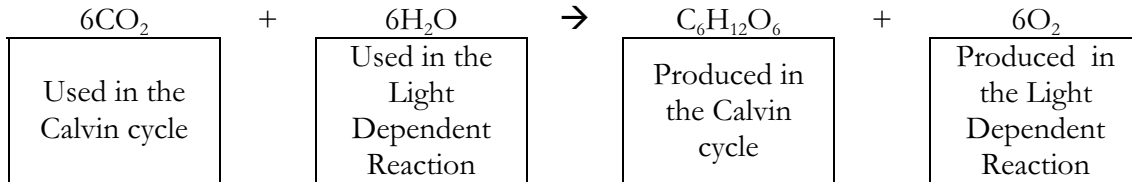
18. Why do the H^+ leak back into the stroma? *Because of the difference in concentration*
19. Through which molecule in the membrane does this leaking process occur and what type of biological molecule is this? *ATP-ase. An enzyme/protein.*
20. What molecule is produced as a result of the H^+ leaking back through the membrane?
ATP
21. How many CO_2 molecules enter the Calvin cycle? *3*
22. What is the first molecule produced after the introduction of CO_2 and how many of these molecules are made? *6 PGA*
23. How many carbon atoms does this molecule contain? *3*
24. How many total carbon atoms are there at this point in the cycle? *18*
25. What is the source of the rest of the carbon atoms (those that aren't from CO_2)? *The three RUBP molecules*
26. What molecule supplies the energy for the reaction that converts PGA to DPGA and by what process was this molecule generated? (Consider all four of the models when answering this question.) *ATP from the Light Dependent Reaction* 
27. Where does the ADP go after the ATP is used in the Calvin cycle? *It is recycled and returned for the light dependent reaction.*
28. What molecule contributes to the conversion of DPGA to Gal3P and by what process is this molecule generated? *NADPH from the Light Dependent Reaction.*
29. Where does the $NADP^+$ go after the NADPH is used in the Calvin cycle? *It is recycled and returned for the light dependent reaction.*
30. Explain in detail, using complete sentences, how the two reactions (light dependent and light independent) depend on each other. *Students should be able to articulate that the ATP and NADPH produced during the light dependent cycle are needed in the light independent cycle, and that the ADP and $NADP^+$ from the light independent cycle are necessary for the light dependent cycle.* 
31. What happens to the six molecules of Gal3P? Be specific and use complete sentences. *1 molecule is used for generating glucose and other molecules, and the other 5 stay in the cycle to regenerate the starting molecules of RuBP.*
32. What molecule supplies the energy for the reaction that converts Gal3P to RuBP and by what process is this molecule generated? *ATP/Light Dependent Reaction*
33. How many carbon atoms are needed to create a single molecule of glucose? *6*

34. How many turns of the Calvin Cycle are required to produce one molecule of glucose? 2

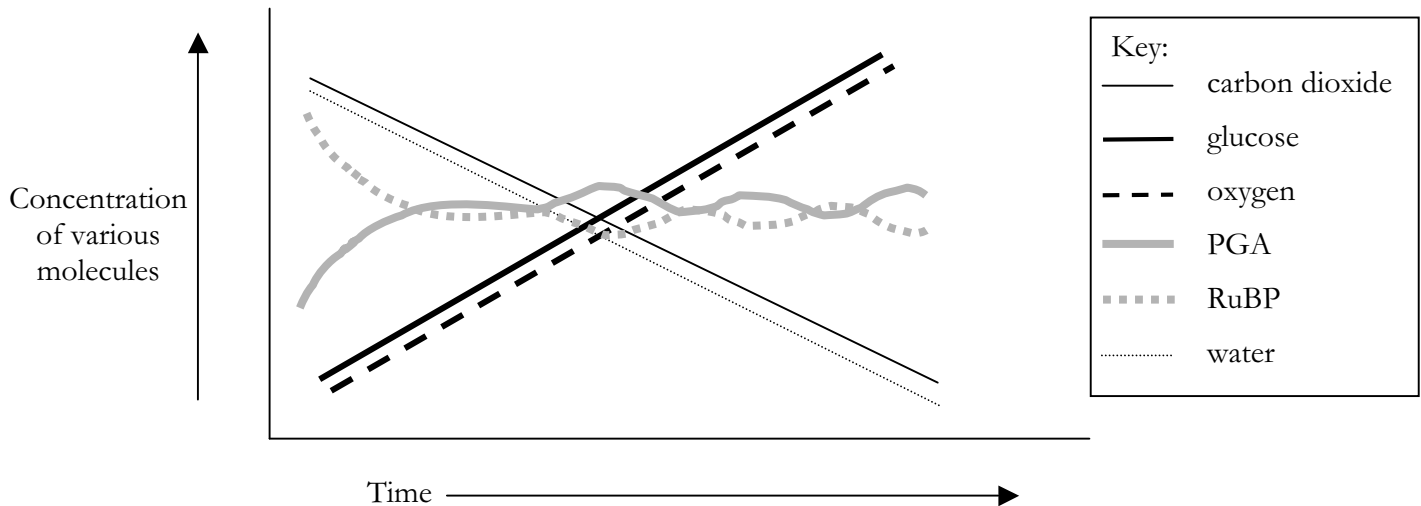


35. How many molecules of NADPH and ATP are needed to produce one molecule of glucose? *For each turn of the cycle you need 9 ATP and 6 NADPH but the cycle turns twice to make one glucose, so a total of 18 ATP and 12 NADPH are needed*

36. Identify under each molecule in the equation, whether they are used or produced and in which reaction, the Light Dependent or Calvin Cycle that occurs.



37. When algae are undergoing photosynthesis, the concentration of various molecules changes within the cells. Graph the concentrations of glucose, carbon dioxide, water, and PGA during a period of active photosynthesis. The concentrations of oxygen, and RUBP have been graphed for you as examples. In this graphical representation, other cellular activities involving these molecules can be ignored.



38. In complete sentences, explain the reasoning behind your completed graph. *Water is being broken down during the light dependent cycle, and carbon dioxide is being broken down during the Calvin cycle, so both of those molecules will decrease in concentration. Conversely, glucose is being produced in the Calvin cycle and oxygen is being released in the light dependent cycle, so the concentrations of these molecules will increase. RUBP is being constantly recycled during the Calvin cycle, so after an initial fall (from a resting state of no Calvin cycle activity), the RUBP concentration will remain fairly constant. Similarly, PGA is produced as long as the Calvin cycle is going, so after an initial rise (from a resting state of no Calvin cycle), it will reach a steady state. [Note: there might be variations in the details*

of the graph, based on when students consider the start point to be, and whether they take into account that oxygen is leaving the cells and carbon dioxide and water are coming in. Thus, it is important to take the explanation into account when considering the accuracy of the graph.]

39. Photosynthesis is typically represented by a simple equation (see Model 1 or question 36). Using the information from this activity explain why this equation is a vastly oversimplified representation of the actual process. *Use individual discretion to accept suitable answers that explain that a complex series of reactions are actually taking place that are separated both spatially and temporally, whereas the equation indicates that by just simply combining water and CO₂ with a sufficient source of energy glucose and oxygen can be produced. Look for depth of understanding in the answer.*