Modeling the Light Independent Reactions
Teacher Preparation

The light independent reactions, also called the Calvin Cycle, are a series of complex molecular changes that occur as the final stage of photosynthesis. During this cycle, carbon dioxide is fixed into an organic compound that can be converted to glucose and other carbohydrates. In this activity, students will construct models of the basic compounds involved in the Calvin Cycle, focusing on the role of carbon and the amount of energy utilized during the process. Prior to doing this assignment, they should already have completed a study of the structure of chloroplasts and the processes that produce energy carriers during the light dependent reactions.

MC.3.B.4- *Describe and model the conversion of light energy to chemical energy by photosynthetic organisms: light independent reactions.*

Student Objectives:

Students will:

- Construct and modify models of carbon compounds involved in the light independent reactions of photosynthesis.
- Know the role of carbon dioxide in photosynthesis.
- Calculate the amount of energy needed in the light independent reactions.
- Relate the energy sources for the light independent reactions to their formation.
- Understand that manufacturing glucose is a complex process.

Materials: Per Group of 2 Students

- 46 Black "Pony" beads — representing carbon atoms
- 26 Purple or Yellow beads — representing phosphates
- 16 White chenille stems — about 6" long
- 24 ATP use "checks" — representing ATP energy required
- 16 NADPH use "checks" — representing NADPH energy required
- 2 small zipper bags
- 2 copies of the lab
- Text or descriptive information

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Preparation Tips:

- Print ATP (24/group of 2) and NADPH (16 /group of 2) checks and cut apart; print lab pages/blank diagrams for each student.
- Cut all of the chenille stems in half.
- Prepare two **zipper bags** for each **group of two students.**
    - Place 48 black beads, 16 chenille stems and 24 ATP energy checks into “Bag 1”.
    - Place 26 yellow (or purple) beads and 16 NADPH energy checks into “Bag 2”.

The amounts listed provide extra beads and checks so that students will have to keep track of what they use as the reaction proceeds. Have extra beads on hand in case any are lost. Determine the total numbers of beads and checks necessary according to the number of student groups in your class.
The molecules constructed can be taken apart and used again in other classes, although you may need to replace chenille stems if they become misshapen.

Prerequisite Knowledge and Pre-lab Discussion:

- <u>Point out to students at the beginning of the activity that the molecules are much more complex than is indicated by the models they will build.</u> The molecules contain other atoms in addition to the carbon and phosphate groups and have been simplified for the activity. You may wish to show students a structural model of RuBP (ribulose biphosphate) or glucose for clarification.
- The names of the molecules involved in the cycle have also been simplified in some cases. For example, the molecule name, 3-Phosphoglycerate, is shortened to 3-PG. The number “3” refers to a location on the molecule where a side branch (or atom) is found. You may want to explain this to students before you begin so that the numbers included in the names do not cause confusion, as they do not relate to the number of carbons present in the models being constructed.
- The students should understand the term “phosphorylation” and know that ATP contains high energy bonds between phosphate groups.
- Students should already have completed activities related to light dependent reactions.
- Be sure that students understand they will track only the carbon atoms and energy carriers (ATP, NADPH) during the reactions, and that the reactions have been simplified in this activity.

Procedures:

- At the beginning of the activity each student will construct three molecules of RuBP and then continue to modify these molecules throughout the cycle as they fill in their diagrams.
- **They must follow the directions carefully. If they become confused tell them to go back and begin again.**
- There are some parts of the activity in which students must calculate the number of beads to remove from the bag, or the number of ATP checks they need. If they are unsure how many they need, point out how that the number is determined by the molecules they are trying to modify.
- **When students finish, the lab partners will combine their information in the creation of a glucose molecule and may need to be reminded that only carbon is shown in their model.**
- If the students become confused they may repeat the activity.

ATP Energy Check **Value = Gain 1 Phosphate** **ATP phosphorylates a molecule.** **ATP – 1 Phosphate = ADP**	**ATP Energy Check** **Value = Gain 1 Phosphate** **ATP phosphorylates a molecule.** **ATP – 1 Phosphate = ADP**
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Student Name ________________________________ **Date _________________**

Modeling The Light Independent Reactions – Student Handout

The light independent reactions, also called the Calvin Cycle, are a series of complex molecular changes that occur as the final stage of photosynthesis. During this cycle, carbon dioxide is fixed into an organic compound that can be converted to glucose and other carbohydrates. In this activity, you and a partner will construct models of the basic compounds involved in the Calvin Cycle, focusing on the role of carbon and the amount of energy utilized during the process. At the end of the activity you and your partner will combine your information to generate the product of photosynthesis and answer questions related to the cycle.

Objectives:

- Construct and modify models of carbon compounds involved in the light independent reactions of photosynthesis.
- Know the role of carbon dioxide in photosynthesis.
- Calculate the amount of energy needed in the light independent reactions.
- Relate the energy sources for the light independent reactions to their formation.
- Understand that producing glucose requires complex chemical reactions.

Materials: For each group of two students.

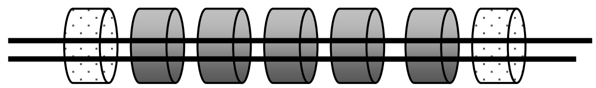
- Two zipper bags of pony beads and energy checks (materials are shared by the group)
    - **Black** –carbon atoms
    - **Purple or Yellow** –Phosphate groups
    - ATP energy use "checks"
    - NADPH energy use "checks"
    - White chenille stems
- Blank diagrams of the light Independent cycle, page 9.
- Textbook

Note: Two students will share the materials in the bags, but each student must construct their own models and fill in a diagram following the instructions on the next 2 pages. Leave materials in the bags until the instructions indicate they should be removed.

Model Construction: Follow each step carefully.

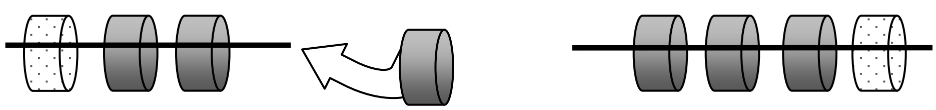
Step: 1- The cycle begins with ribulose biphosphate, RuBP.

- **Construct 3 models** of RuBP as shown in the diagram below. Hold two chenille stems together and slide five black carbon beads onto the stems. Add a phosphate bead to each end.
- **Draw one** of these molecules on your diagram in the box at "Step 1" and indicate you have made three of them by writing **"X 3"** (this means "times 3").
- **Shade** the carbon beads and leave the phosphates white as shown below.
- **Label it**: RuBP.



Step: 2- Carbon dioxide molecules enter the cycle and are "fixed" into each RuBP molecule. The new molecule is unstable and breaks apart.

- **Locate CO_2** entering the cycle on your diagram. Indicate that three molecules entered the cycle. (Write "X 3").
- **Remove** carbon beads from the bag to represent carbon dioxide entering the cycle.
- Carefully slide the two chenille stems apart keeping the three carbon beads and one phosphate bead on one stem, as shown below.
- "Fix" the CO_2 by adding a carbon bead to the other stem, so that each stem has three carbons, as shown below. Repeat the steps above with all molecules.
- **Draw one** of these molecules in the box at Step 2 and indicate how many you have.
- **Label it**: 3-PG (This is 3-Phosphoglycerate)



Step: 3- During Phosphorylation, one phosphate from ATP is added to **each** molecule of 3-Phosphoglycerate. (ATP – Phosphate = ADP)

- Use one "ATP Check" to "buy" each phosphate you will need. **Remove the "ATP Checks"** from the zipper bag and place them near your diagram.
- **Write** the number of ATP molecules required on the diagram near Step 3.
- **Remove** the phosphate beads you "bought" from the bag and add one phosphate bead to the end of **each** molecule stem.
- **Draw** the new molecule in the Step 3 box on your diagram and indicate how many you have by using an "X" and the number.
- **Label it**: 1-3-PG (1-3-Phosphoglycerate)

Step: 4- Phosphate will now be removed from each molecule. NADPH is used in this process, and is converted to NADP+

- Use one “NADPH Check” to buy each phosphate so that **one** can be **removed** from **each** molecule. Return the phosphate beads to the bag.
- Count and remove the “NADPH Checks” needed from the bag and place them near your diagram.
- **Write the number of NADPH** required on your diagram beside Step 4.
- **Draw** the new molecule in the Step 4 box on the diagram and indicate the number you have with an “X” and the number.
- **Label it**: G3P (Glyceraldehyde 3-phosphate)

Step: 5- One G3P will now leave the cycle and be available to generate glucose.

- **Set aside one G3P** molecule and save it for use later. This is the product of the Light Independent Reactions and will be used to create glucose.
- **Draw and label a G3P** molecule on your diagram in the Step 5 box. Draw an arrow to show it is leaving the cycle.

Step: 6- The remaining G3P will be used to regenerate **RuBP**. This requires energy and a phosphate from ATP.

- **Draw and label a G3P** molecule in the box at Step 6. Indicate the number **remaining** in the cycle.
- **Three ATP molecules are expended** during the rearrangement of G3P to recreate the RuBP that will continue the cycle.
- **Remove 3 “ATP Checks”** from the baggy and add them to your stack.
- **Draw an arrow** near Step 6 and label it to show that three ATP have been used.
- **Re-create RuBP** by rearranging the beads on your chenille stems. Remove the necessary phosphate beads and stems from the bag in order to make the RuBP molecules.
- **Refer to Step 1** for the structure if necessary. (RuBP is already on your diagram. Do not draw it on the diagram again.)

You and a partner will combine the information from your completed diagrams to answer the analysis questions on the next page.

You will use the G3P molecule models you set aside in step 5.

Do not replace any of the materials still on your desk until you answer all the questions.

Name ______________________________ Date ________________

Analysis and Questions: Light Independent Reactions – Student Handout

Your diagram should be finished at this point. You should have a stack of ATP and NADPH Checks that you accumulated during the activity. You will also have one G3P molecule and the newly created RuBP molecules that will continue the cycle.

Questions: Work with your partner to determine answers to the following questions. Remember to combine the information on both diagrams to arrive at your answers.

1. With your partner create a glucose model with the remaining G3P models made in the light independent cycle. Glucose is a 6-carbon sugar but does not contain any phosphate. What was removed from the molecule to form glucose?

2. Glucose contains other elements not shown in your model. What is the actual chemical formula of glucose?

3. How many total carbon dioxide molecules were required to generate one glucose molecule?

4. Calculate the total number of ATP molecules required to manufacture one glucose molecule?

5. How many NADPH molecules were required to make one glucose molecule?

6. What is the source of the ATP and NADPH molecules required in this cycle?

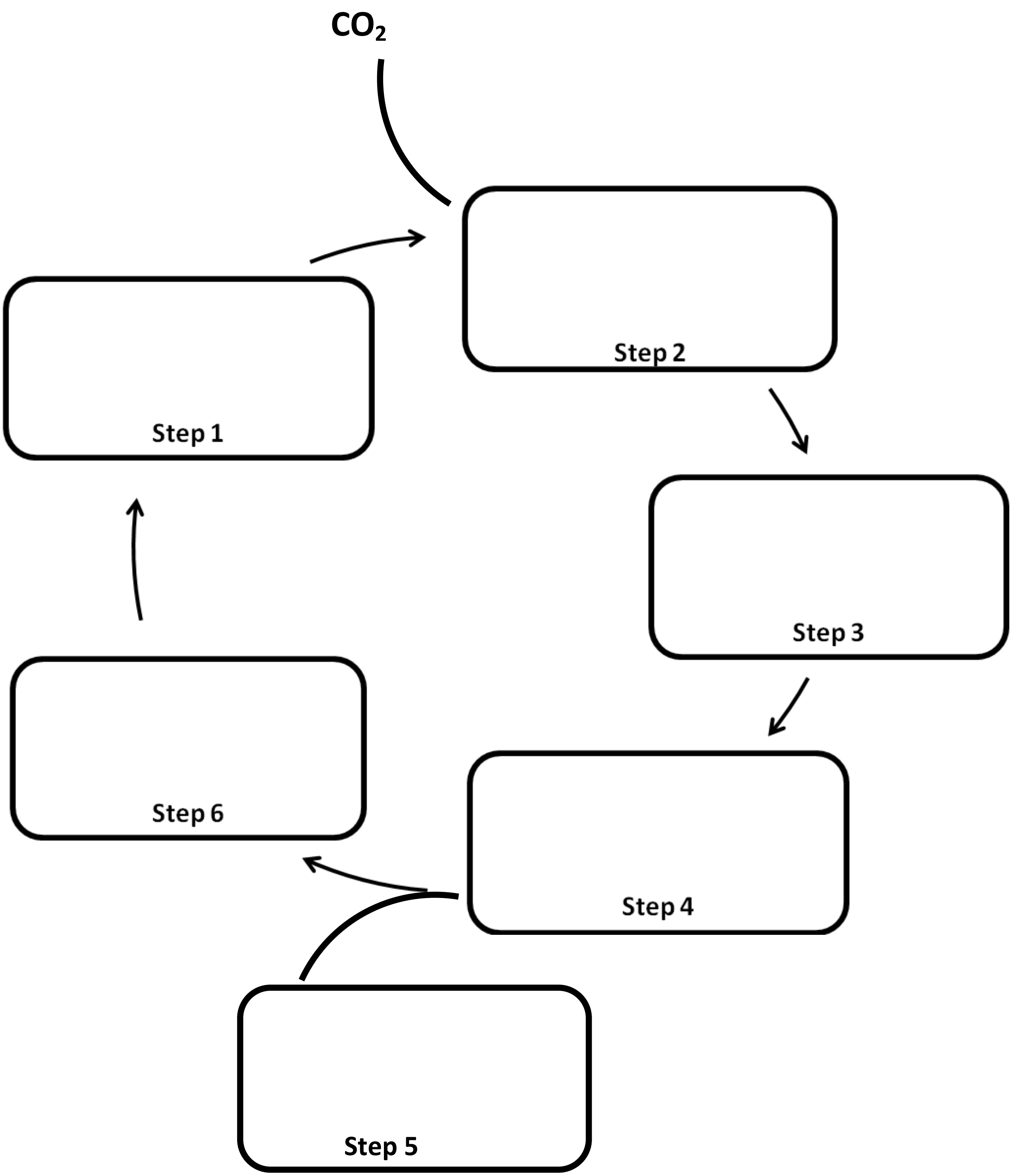
7. What happens to most of the carbon involved in the light independent cycle?

8. An enzyme called Rubisco is required to 'fix" carbon dioxide into RuBP. What does it mean to "fix" carbon into RuBP?

9. Is the creation of glucose as simple as the formula of photosynthesis makes it seem? Explain your reasoning.

Name ________________________________ **Date** ___________________

Light Independent Reactions Diagram – Student Handout



Teacher Explanation: Light Independent Reaction Diagram

- At the beginning of the cycle, during carbon "fixation", RuBP combines with carbon dioxide. The carbon is added as a "branch" on the RuBP molecule. Afterward, RuBP breaks apart. It would be difficult to demonstrate this the way these molecules are constructed. Therefore, students broke the RuBP first and then added the carbon from carbon dioxide.
- Rubisco, an enzyme required to "fix" carbon into the RuBP molecule is one of the most abundant substances on the planet. Enzymes are compounds that catalyze reactions, such as the breaking apart of large molecules to form smaller ones. If students have not studied enzymes direct them to necessary text material.
- Every "turn" of the Calvin Cycle adds one more carbon dioxide into the cycle. So, every three turns makes a new three-carbon G3P (PGAL) molecule. This means that six turns through the cycle would give you enough carbon to make a glucose molecule! This is why groups of two students are able to combine their work and create one glucose molecule after the activity.
- For every G3P (PGAL) molecule made, it takes nine molecules of ATP and six NADPH. If students combine their work, it will require 18 ATP, and 12 NADPH to generate enough G3P to manufacture one glucose molecule.
- Sugar (glucose) is not made during photosynthesis, but the molecules necessary are (G3P). The G3P (GPGAL) molecules can be used to make other carbohydrate compounds the plant needs; glucose, starch, cellulose etc.
- <u>Student Learning Goals</u>: The students should note the reactions are very complex requiring many changes and the necessary enzymes. They should identify the sources of the materials required to complete the cycle, i.e. carbon dioxide, ATP and NADPH. They should know the basic structure of glucose.

Light Independent Reactions
Key to Analysis and Questions

1. Phosphate was removed.

2. The formula for glucose is $C_6H_{12}O_6$.

3. 6 molecules of carbon dioxide are required for generation of one glucose molecule.

4. 18 ATP molecules are required to generate one glucose molecule.

5. 12 molecules of NADPH are required to generate on glucose molecule.

6. The ATP and NADPH required in the light independent reactions is generated during the **light dependent reactions** of photosynthesis.

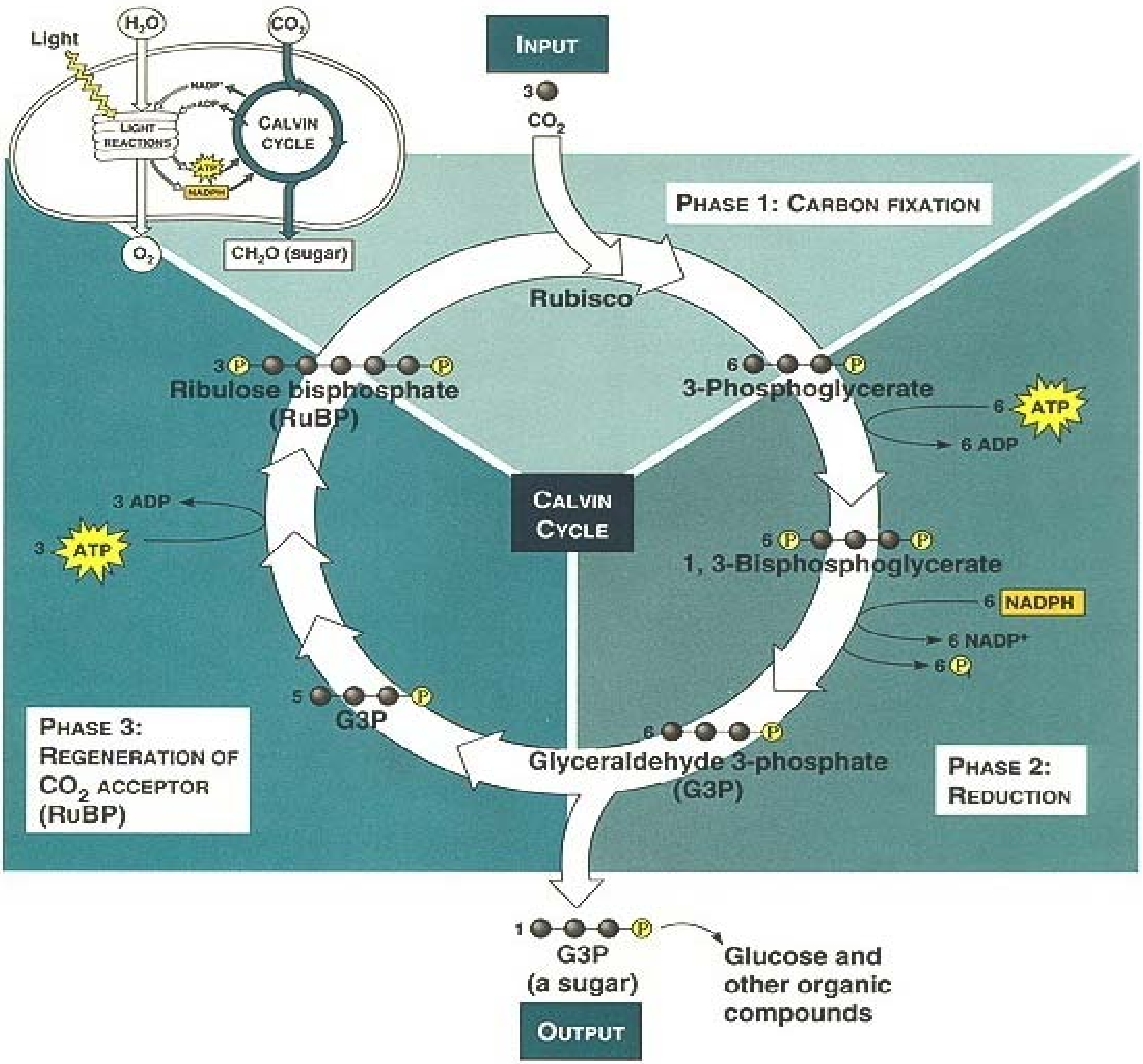
7. Most of the carbon involved in the light independent reaction cycle is used to regenerate the RuBP that continues the cycle.

8. When carbon is “fixed”, the atoms from carbon dioxide gas become part of the RuBP molecule to form an unstable 6-carbon compound that quickly degenerates into two 3-PG molecules.

9. Formation of glucose is a complex process that requires many changes in carbon molecules. It would actually require showing many chemical reactions to demonstrate what happens.

Teacher Diagram of the Light Independent Reactions

Source: https://www.msu.edu/~smithe44/calvin_cycle_process.htm
(The website includes a complete explanation and pictures of molecules constructed with ball-stick model kits.)



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