Biology Magnets Module 3: Photosynthesis and Respiration - Teacher and Student Guides

Teacher Information

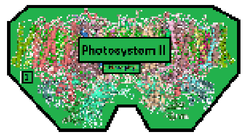
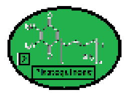
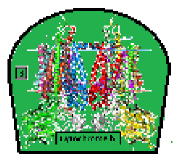
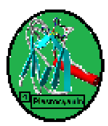
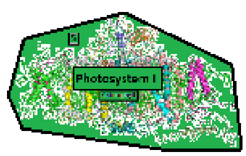
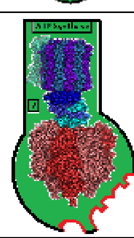
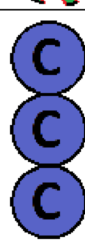
This module uses magnets designed for teacher and student interaction to guide learning the various classes of organic molecules. In this guide are outlines of lessons that can each last from 10 minutes to an entire class period, depending upon teacher preference. The lesson has both teacher-centered and student-centered activities. The student-centered activities are most effective if students are in small groups. It may be necessary to have multiple magnet sets for large classes. A student handout is provided which can be printed out and given to each student group to help guide their progress as they work with the magnets. If budget or white board space is limited, groups can alternate between using a set of magnets and doing other activities. Teachers can refer to the videos posted at the Biology Magnet web site at Biologymagnets.com for further teaching instructions.

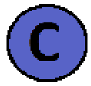
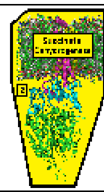
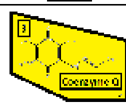
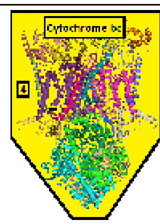
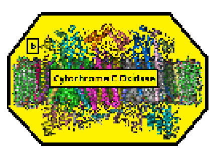
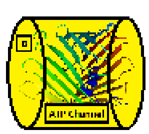
Magnet Care and Maintenance

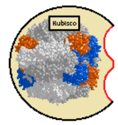
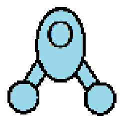
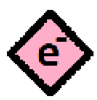
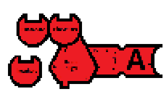
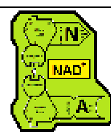
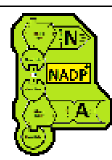
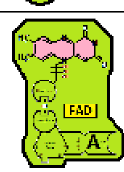
Biology magnets are made to last for years. Periodically magnets will fall off or are knocked off the plastic. A piece of magnetic tape is included with each module, which should be able to replace around 10-12 magnets if necessary. Simply cut a new magnet and peel off the back to replace. Magnetic tape can be purchased from a hobby store to replace magnets lost over time. Laminate may peel off, especially on small pieces. Transparent tape can be used as a replacement or to re-attach laminate that comes loose by curling the tape over the back of the magnet. The machines used to cut Biology Magnets are not always perfectly accurate. Sometimes a bit of white or black outline on the edges occurs or a cut might be slightly off center. Use scissors to remove extra outline that is unnecessary if desired. Store magnets in the clasp envelopes in which they arrived for easy organization.

Photosynthesis/Respiration Copyright Information

Biology Magnets Module 3 Materials List

Magnet Name	Quantity	Picture	Function	Location
Photosystem II	1		Absorbs sunlight with chlorophyll, transports electrons	Electron transport chain on thylakoid membrane
Plastoquinone	1		Electron transport	Electron transport chain on thylakoid membrane
Cytochrome B	1		Electron transport, hydrogen pumping	Electron transport chain on thylakoid membrane
Plastocyanin	1		Electron transport	Electron transport chain on thylakoid membrane
Photosystem I	1		Absorption of sunlight with chlorophyll, electron transport	Electron transport chain on thylakoid membrane
Ferredoxin NADP Reductase	1		Electron transport, reduces NADP to NADPH	Electron transport chain on thylakoid membrane
ATP Synthase	1		Proton channel, converts ADP + P to ATP	Thylakoid membrane
3-carbon chain (helps make RUBP)	4		Carbon atoms that make up RuBP in Calvin Cycle	Stroma of chloroplast

Magnet Name	Quantity	Picture	Function	Location
Carbon atom	13		Represents carbon dioxide and carbon atoms involved in Calvin cycle and respiration	Stroma of chloroplast, in mitochondrion throughout respiration
NADH Dehydrogenase	1		Accepts electrons from NADH in mitochondrial electron transport chain. Pumps hydrogen into intermembrane space.	Electron transport chain on mitochondrial inner membrane.
Succinate Dehydrogenase	1		Accepts electrons from $FADH_2$ in mitochondrial electron transport chain.	Electron transport chain on mitochondrial inner membrane.
Coenzyme Q	1		Electron transport	Electron transport chain on mitochondrial inner membrane.
Cytochrome bc	1		Electron transport, pumps hydrogen ions from matrix to intermembrane space	Electron transport chain on mitochondrial inner membrane.
Cytochrome c	1		Electron transport	Electron transport chain on mitochondrial inner membrane.
Cytochrome C Oxidase	1		Electron transport, pumps hydrogen ions from matrix to intermembrane space, catalyzes transfer of electrons to oxygen to form water	Electron transport chain on mitochondrial inner membrane.
ATP Synthase	1		Proton channel, converts ADP + P to ATP	Mitochondrial inner membrane.
ATP Channel	1		Allows ATP to exit mitochondrion	Between inner and outer mitochondrial membrane

Magnet Name	Quantity	Picture	Function	Location
Coenzyme A	1		Binds to acetyl group in preparatory reaction	Matrix of mitochondrion
Rubisco	1		Attaches CO_2 to RUBP	Stroma of chloroplast
Oxygen Atom with extensions	1		Attaches to two hydrogens and two electrons to form water or to another oxygen atom to form O_2	Thylakoid space, at end of electron transport chain in mitochondrion.
Hydrogen ion (proton)	18		In and around thylakoid to form concentration gradient, carried by water, carried by electron transporter molecules, part of glucose	Various locations
Electron	12		Part of water molecules, moves down electron transport chains, part of electron carrier molecules	Various locations
ADP + P	5 + 5		Bind together to form ATP at ATP synthase proteins	Stroma, matrix of mitochondrion, cytoplasm of cell
NAD	4		Accepts electrons and hydrogen ions from breakdown of glucose	Matrix of mitochondrion, cytoplasm of cells
NADP	3		Accepts electrons and hydrogen ions from electron transport chain on thylakoid membrane	Stroma
FAD	1		Accepts electrons and hydrogen ions from breakdown of glucose	Matrix of mitochondrion, cytoplasm of cells
3” Magnetic Tape Strip	1		Used to replace lost magnets	
Total Pieces	**84**			

Lesson 3A – Light Reactions of Photosynthesis (20-80 minutes)

Teacher-Centered Activity (20-30 minutes): This lesson reviews the light reactions of photosynthesis using the Biology Magnets from Module 3 as shown in the table above. It is useful to write the photosynthesis equation (**Figure 3.A.1**) on the board and refer to it as the processes occur. Start this lesson by drawing a large oval on the board to set up the thylakoid membrane model with the Biology Magnets (**Figure 3.A.2**). It would be helpful to have a discussion of where the thylakoid membrane is located (within a leaf, within a cell, within a chloroplast) and if possible a diagram showing the process of the light reactions. The process starts with sunlight hitting the two photosystems, causing the electrons in the photosystems to move down the electron transport chain. As they move, the plastoquinone and cytochrome complexes use the energy from the electrons to pump hydrogen ions from the stroma into the thylakoid space. As the electrons reach the end of the chain, $NADP^+$ picks them up in addition to a hydrogen ion, to become NADPH. The electrons that came from the photosystems must be replenished. Photosystem I receives the electrons that originated in photosystem II, and photosystem II receives electrons from a water molecule located in the thylakoid space, which breaks apart to release hydrogen ions. After this happens twice, two oxygen atoms (from the water molecules) combine to form O_2, which can go through the membrane and exit the cell. A buildup of H^+ ions now exists in the thylakoid space. Those ions will move out through the ATP synthase complex. There are binding sites on the ATP synthase for ADP and P. When the H^+ ions move through, the ATP synthase protein binds ADP and P together to form ATP. At the end of the process, NADPH and ATP have been formed which will be used in the Calvin Cycle to make glucose (**figure 3.A.3**).

Figure 3.A.1 – The Photosynthesis Equation
$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$
Carbon dioxide + water -> glucose + oxygen

Figure 3.A.2 – Light Reactions of Photosynthesis Initial Biology Magnet Positions

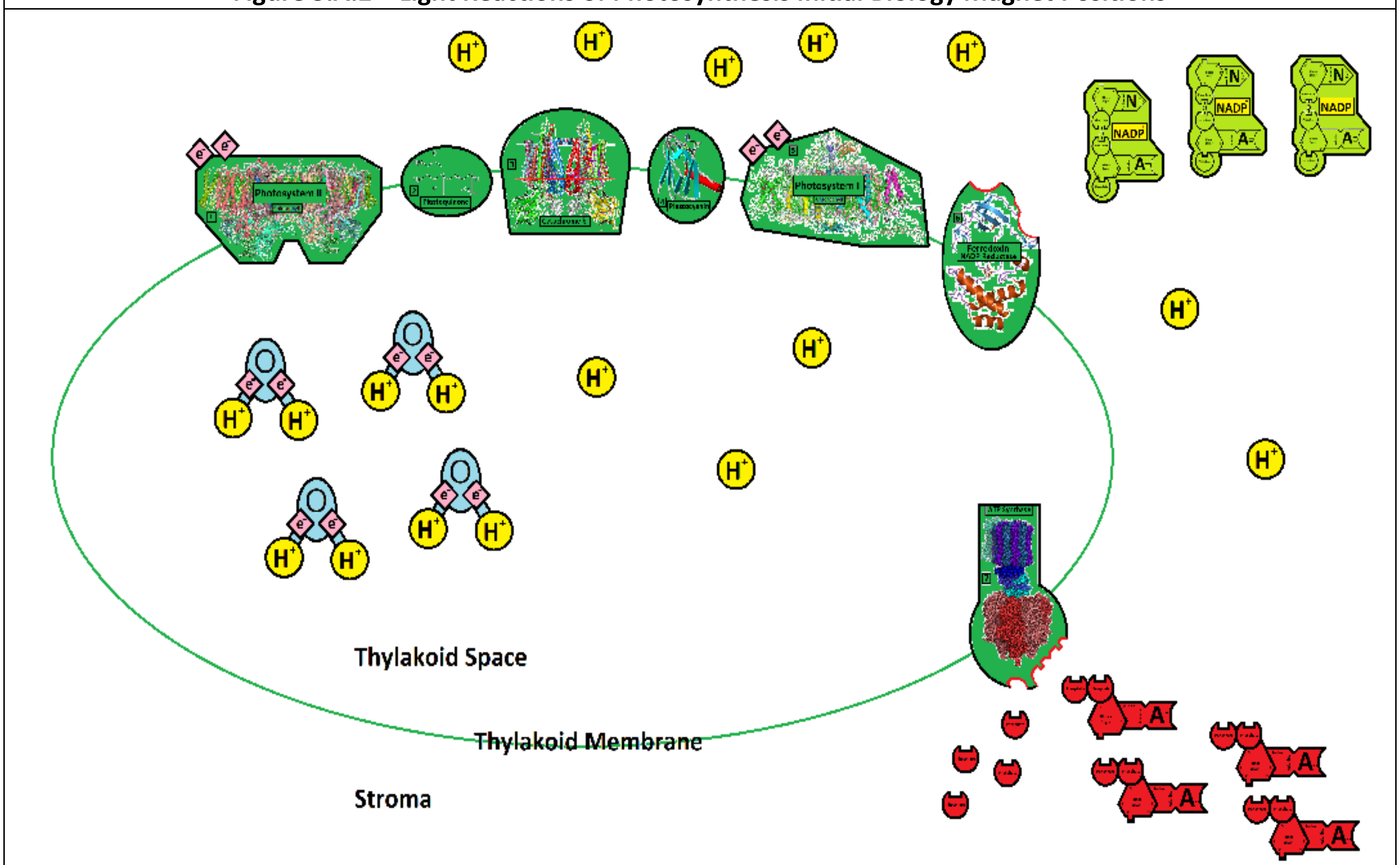
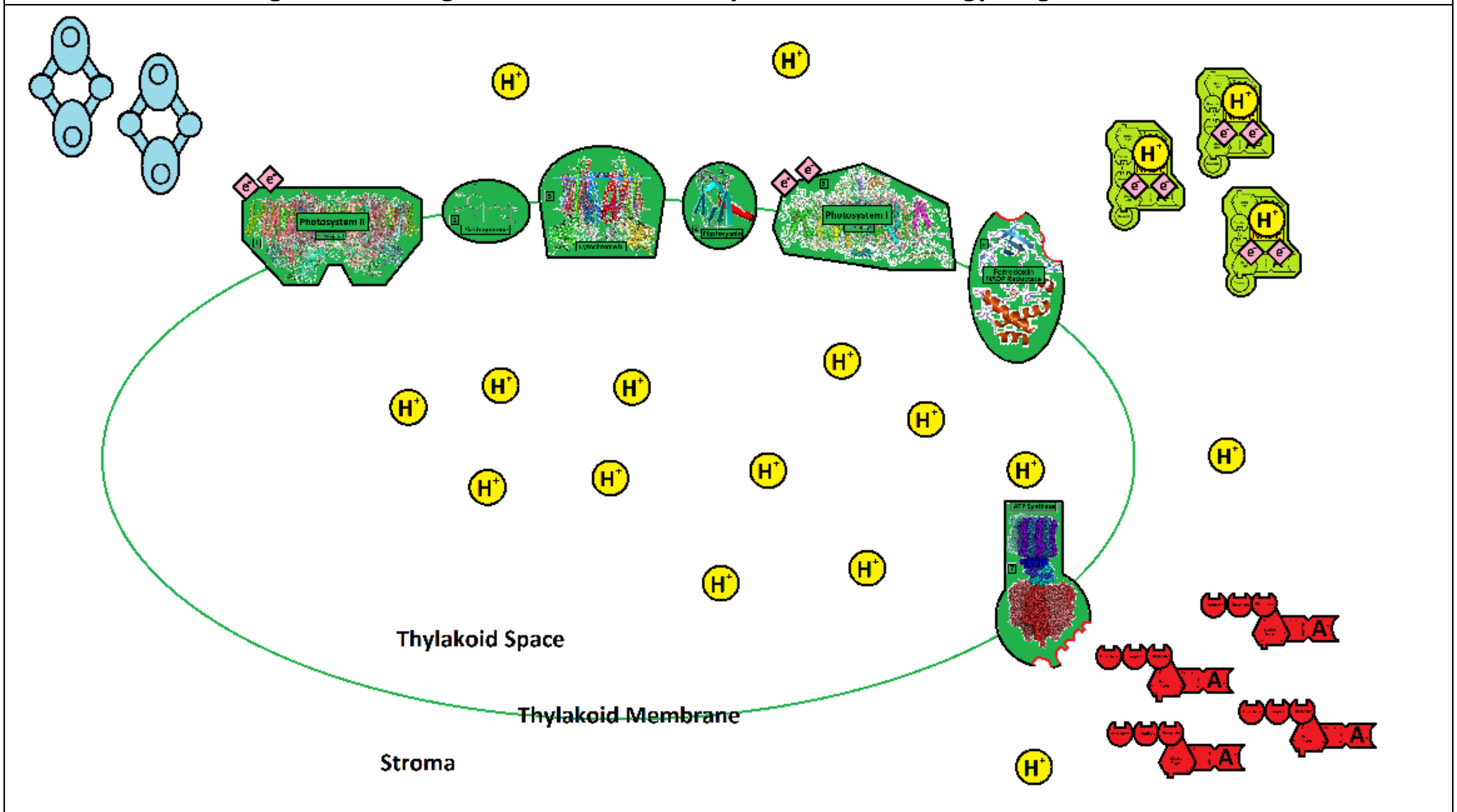


Figure 3.A.3 – Light Reactions of Photosynthesis Final Biology Magnet Positions



Student Centered Activity (20-50 minutes): After teaching the light reactions, put students into small groups. A copy of the student guide for the light reactions may be given to each group if necessary for guidance. Have the students set up the thylakoid and take turns moving the magnets and carrying out the processes of the light reactions. Allow the students to help one another. Repeat until all students have shown mastery without using the student guide.

Extra exercises: Cyclic Pathway of Photosynthesis – In the cyclic pathway of photosynthesis, only photosystem I produces energized electrons which go to the ferredoxin, then the cytochrome complex, then plastocyanin, and finally back to photosystem 1. The cytochrome complex uses the energy to move hydrogen ions into the thylakoid space, but no water is broken down and no NADPH is produced. ATP is still made as hydrogen ions move through ATP synthase. It is a way ATP can be made by photosynthesis without producing oxygen.

Hypothetical Situations - Ask the students individually or in groups to use the model to consider what might happen to the products of the light reactions in the following scenarios:

1. The plant is in the dark – ans: Electrons will not move down the membrane, so no products will be produced
2. The ATP synthase protein is mutated so ADP will not bind to it - ATP will not be produced, but oxygen and NADPH will continue to be produced.
3. The thylakoid membrane has a hole in it - Hydrogen ions will move out through the hole instead of through ATP synthase. No ATP will be made but NADPH and O_2 will be produced.
4. Plastoquinone and/or cytochrome b are mutated so they will move electrons but won't pump hydrogen - Hydrogen will not build up in the thylakoid space so the ATP synthase protein will make no ATP. NADPH and O_2 will still be produced.
5. Magnesium deficiency causes the cell not to be able to make chlorophyll - As in scenario 1, light will not be absorbed so electrons will not move down the membrane, and no products will be produced.
6. NADP reductase is mutated and will not function - No NADPH will be made but ATP and O_2 will still be produced at first. Quickly electrons will get "backed up" and have nowhere to go, and no products will be made.

Lesson 3B – Calvin Cycle of Photosynthesis (15-60 minutes)

Teacher-Centered Activity (15-30 minutes): This lesson picks up where the light reactions finished. It would help to review the parts of the chloroplast first so the students can internalize the location of this activity. It would also help to show a diagram of the Calvin cycle as is shown in a textbook and review what happens in each part of the diagram as the lesson progresses. Start by placing the carbon atom magnets on the board to form three RUBP molecules and many (at least six) CO2 molecules in the stroma of the chloroplast (**Figure 3.B.1**) First, demonstrate carbon fixation by attaching three of the CO2 carbon atoms to the RUBP molecules using the Rubisco enzyme. This forms three 6-carbon compounds that immediately break down into six 3-carbon compounds known as phosphoglycerate (PGA). Pull the 6-carbon compounds apart into 3-carbon compounds. (**Figure 3.B.2**). In the reduction portion of the reaction, ATP and then NADPH act upon the PGA to donate phosphates, electrons, and hydrogen ions to the PGA to form 6 molecules of glyceraldehyde 3-phosphate (G3P). Demonstrate this by using the ATP and NADPH formed in the light reactions to transfer the magnets to the PGAs. (**Figure 3.B.3**). One of the G3P molecules gets stored away and the other 5 are used for the regeneration of RUBP phase, again by using ATP from the light reactions. Demonstrate this with the molecules by putting aside a G3P and rearranging the rest of the carbon magnets back to the original RUBP structure. The ADP molecules and the NADP molecules return to the light reactions to be recycled. Complete the process again and there will be two G3P molecules stored away. The two G3P molecules lose their phosphate groups and bind together to form glucose (**Figure 3.B.4**). The glucose molecule starts the upcoming respiration lesson.

Figure 3.B.1 – Position of Biology Magnets at the start of the Calvin cycle

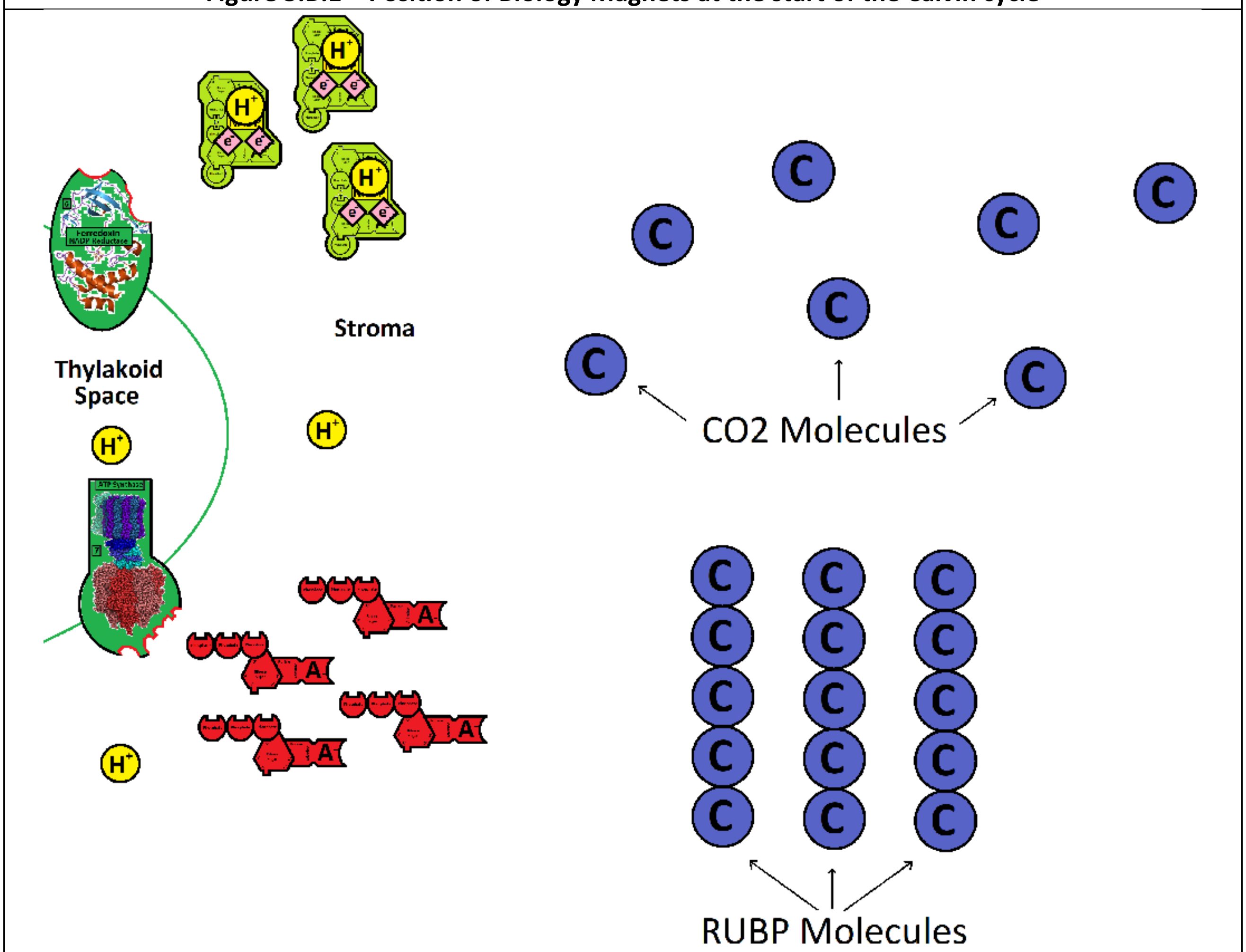


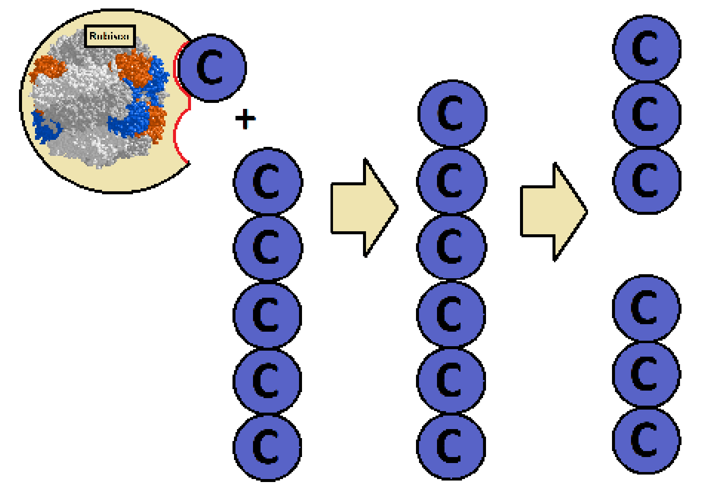
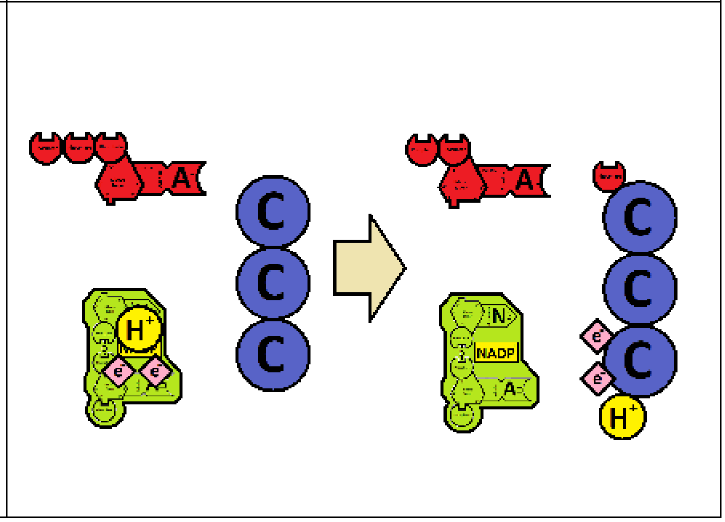
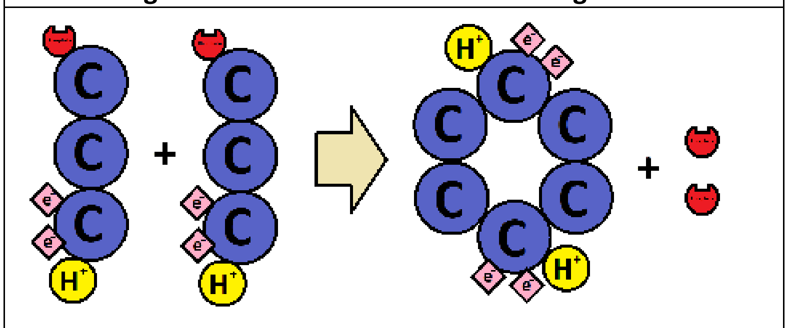
Figure 3.B.2 – Carbon Fixation Process	Figure 3.B.3– Reduction Process
	

Figure 3.B.4 – G3P combines to form glucose



Student Centered Activity (10-30 minutes): After teaching the light reactions, put students into small groups. A copy of the student guide for the Calvin cycle may be given to each group if necessary for guidance. Have the students set up the magnets as seen in Figure 3.B.1 and take turns moving the magnets to carry out the processes of the Calvin Cycle. Allow the students to help one another. Repeat until all students have shown mastery without using the student guide.

Extra exercises – C3 vs. C4 photosynthesis – To represent C4 photosynthesis using magnets, use one of the 3-carbon group magnets to represent phosphoenolpyruvate (PEP) in the mesophyll cells, which binds CO2 to make a 4-carbon molecule called oxaloacetic acid (OAA). The 4-carbon compound can be transported to bundle sheath cells to release the CO2 for use in the Calvin Cycle.

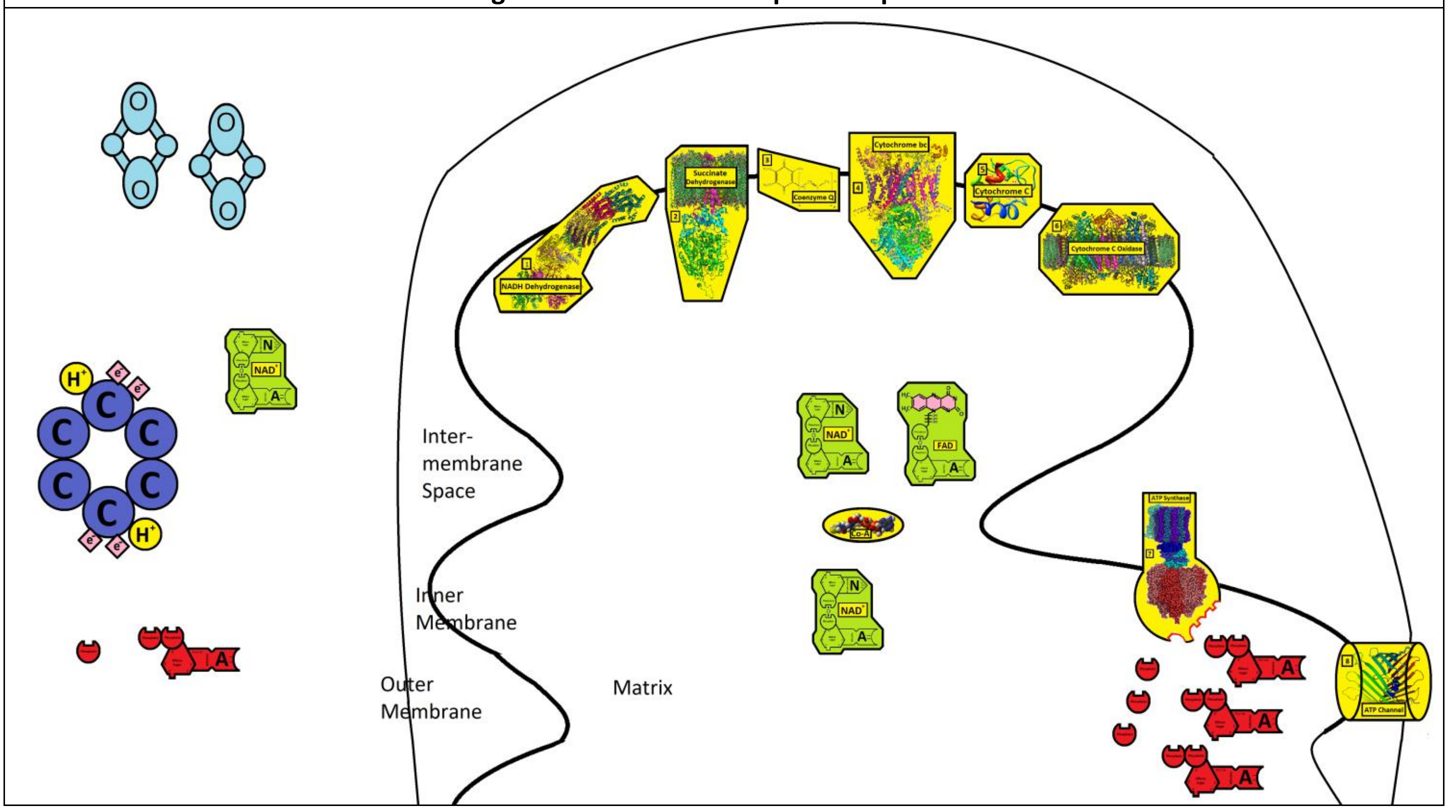
Hypothetical Situations: As a group, consider what might happen to the process of the Calvin cycle in the following scenarios. Write down your answers and tell/show your teacher the answers when you finish.

1. The plant is in the dark – ans: The cycle will continue if ATP and NADPH are present. If these are depleted the cycle will stop.
2. The Rubisco protein is mutated so it cannot attach to CO_2 – ans: There will be no carbon fixation if Rubisco is mutated. PGAL will not be formed. ATP and NADPH will not be used.
3. There are low levels of RUBP in the stroma – ans: Low levels of RUBP would cause fewer PGALs to be made. The more RUBP present, the more glucose will be made
4. There is NADPH but no ATP – ans: Carbon fixation would occur but reduction reactions would not. The cycle will stop.
5. Stomata in the leaves are closed lowering the levels of CO_2 – ans: Less CO_2 will slow the formation of glucose. The Calvin cycle still turns but more slowly.
6. Due to burning of fossil fuels, there are higher levels of CO_2 – ans: Higher CO_2 levels will increase the speed of formation of glucose. Experiments with plants have confirmed this is true.

Lesson 3C – Respiration and the Breakdown of Glucose (20-80 minutes)

Teacher-Centered Activity (20-40 minutes): This lesson picks up where the Calvin cycle finished. It would help to review the parts of the mitochondrion first so the students can internalize the location of this activity. It would also help to show a diagram of respiration and the chemical equation as is shown in a textbook and review what happens in each part of the diagram as the lesson progresses. Start by drawing a large inner and outer mitochondrial membrane and place the respiration magnets on the board, with a glucose molecule outside of the mitochondrion (**Figure 3.C.1**). Explain that the glucose molecule has a large supply of hydrogen ions (protons) and electrons, more than can be represented with the magnets.

Figure 3.C.1 – Initial Setup for Respiration



Part 1 - Glycolysis - There are many steps in glycolysis, but this is a simplified model that covers the necessary levels of understanding for basic biology courses. Glycolysis occurs in the cytoplasm outside of the mitochondrion. Demonstrate glycolysis by breaking the glucose apart to form two 3-carbon molecules called pyruvate. Move electrons and a hydrogen ion from the glucose to an NAD to form NADH, and put together ADP + P to form ATP. The NADH will move into the mitochondrion to the electron transport chain (two NADHs are actually formed in glycolysis and two ATPs. This can be demonstrated but it may be cumbersome to do so with too many magnets on the board) (**Figure 3.C.2**).

Part 2 – Preparatory Reaction – For the preparatory reaction, move a pyruvate molecule into the matrix of the mitochondrion and have it attach to the Co-A (coenzyme A) magnet. Remove a carbon atom from the structure and have it leave the mitochondrion. That carbon represents CO_2 released by respiration. Another NADH will be formed here from electrons and a hydrogen ion binding with the NAD+. The new molecule formed is called acetyl-CoA (**Figure 3.C.3**). Remind students that this process happens twice, with each pyruvate (this can be demonstrated but it may be cumbersome).

Figure 3.C.2 – Glycolysis

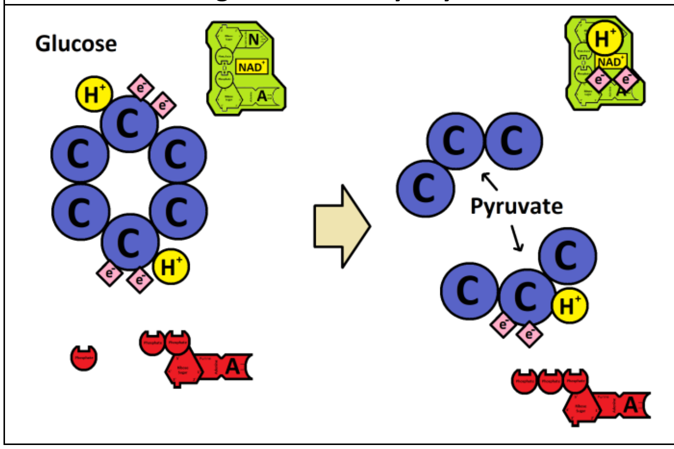
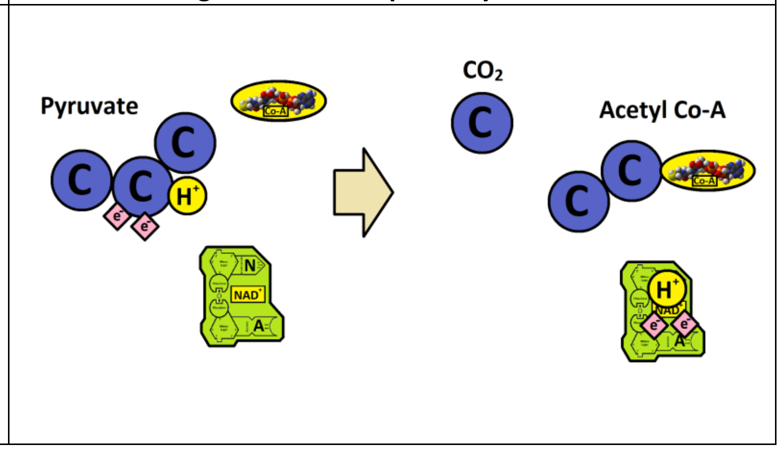
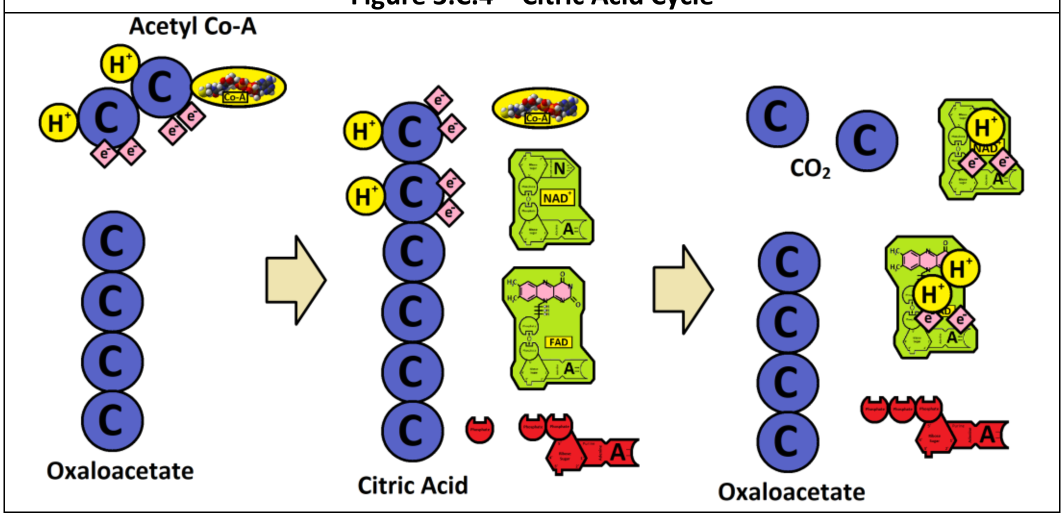


Figure 3.C.3 – Preparatory Reaction



Part 3 – Citric Acid Cycle – There are many steps in the citric acid cycle, but this is a simplified model that covers the necessary levels of understanding for basic biology courses. The Citric Acid Cycle happens in the matrix of the mitochondrion. First, add more electrons and hydrogens to the acetyl-CoA molecule. Explain that these were always present in the glucose, it was just too cumbersome to show and be able to move the magnets around. Attach the acetyl group to the 4-carbon oxaloacetate molecule, releasing the CoA. This forms citric acid. The citric acid is gradually broken down by enzymes, yielding electrons and hydrogen atoms to form NADH and FADH2. Two carbon atoms are released as carbon dioxide and exit the mitochondrion. The oxaloacetate remains at the end of the cycle. More ATP is also made during this breakdown. The original glucose has been completely broken down into CO2 atoms, ATPs, and several electron carriers (NADH, $FADH_2$). The electron carriers will be used to start the electron transport chain in the next lesson (**Figure 3.C.4**).

Figure 3.C.4 – Citric Acid Cycle



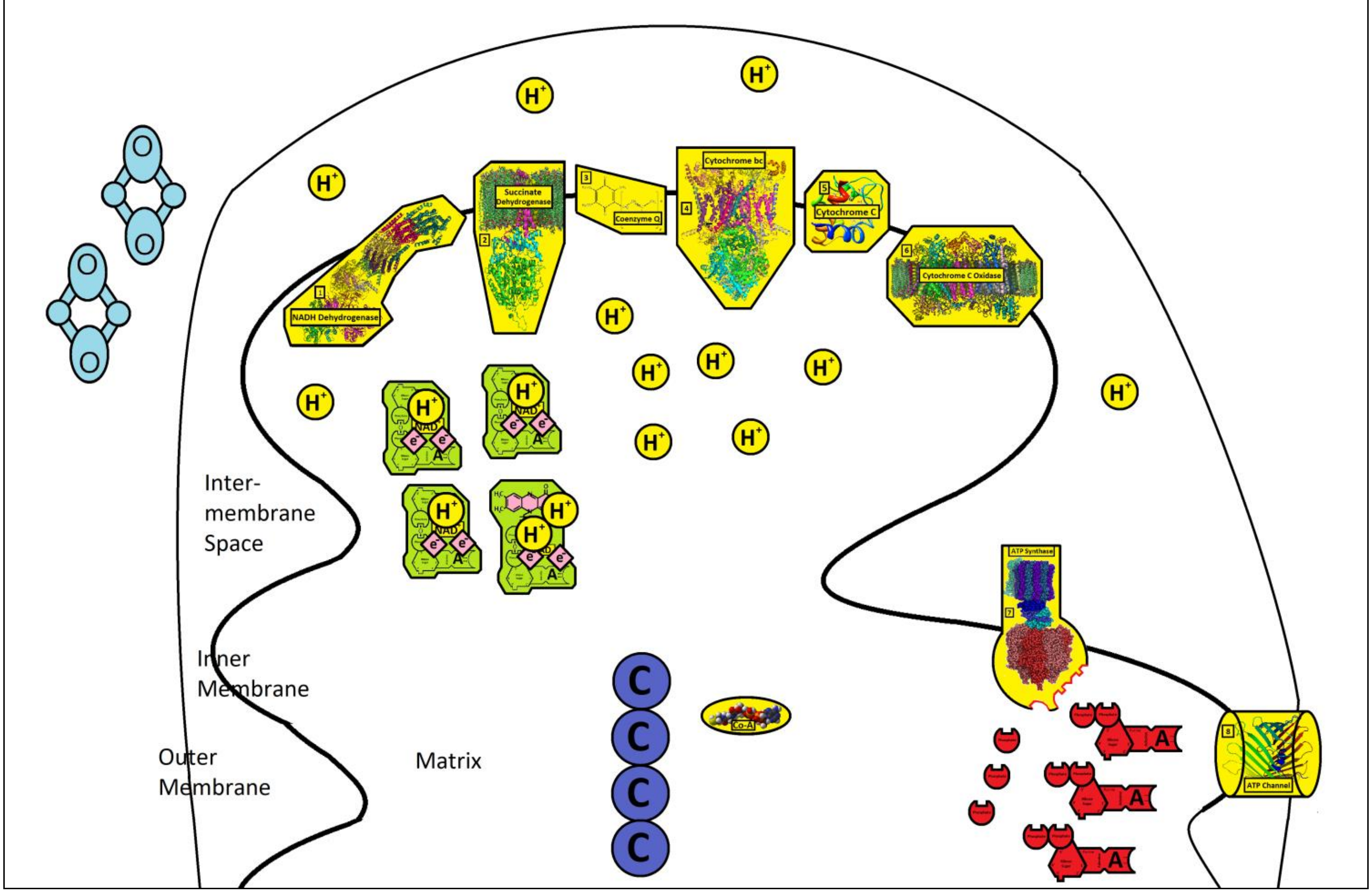
Student Centered Activity (20-40 minutes): After teaching the breakdown of glucose, put students into small groups. A copy of the student guide for the lesson may be given to each group if necessary for guidance. Have the students set up the magnets as seen in **Figure 3.C.1** and take turns moving the magnets and carrying out the processes of the breakdown of glucose. Allow the students to help one another. Repeat until all students have shown mastery without using the student guide.

Extra exercise: Fermentation – After glycolysis, demonstrate fermentation by having the pyruvate take back hydrogens and electrons from NADH in the cytoplasm instead of taking them to the mitochondrion. To show alcoholic fermentation in plants, remove a carbon atom from the pyruvate and release it, leaving a two-carbon alcohol (ethanol) molecule. The extra carbon represents the CO_2 released in alcoholic fermentation.

Lesson 3D – Respiration and the Electron Transport Chain in the Mitochondrion (20-80 minutes)

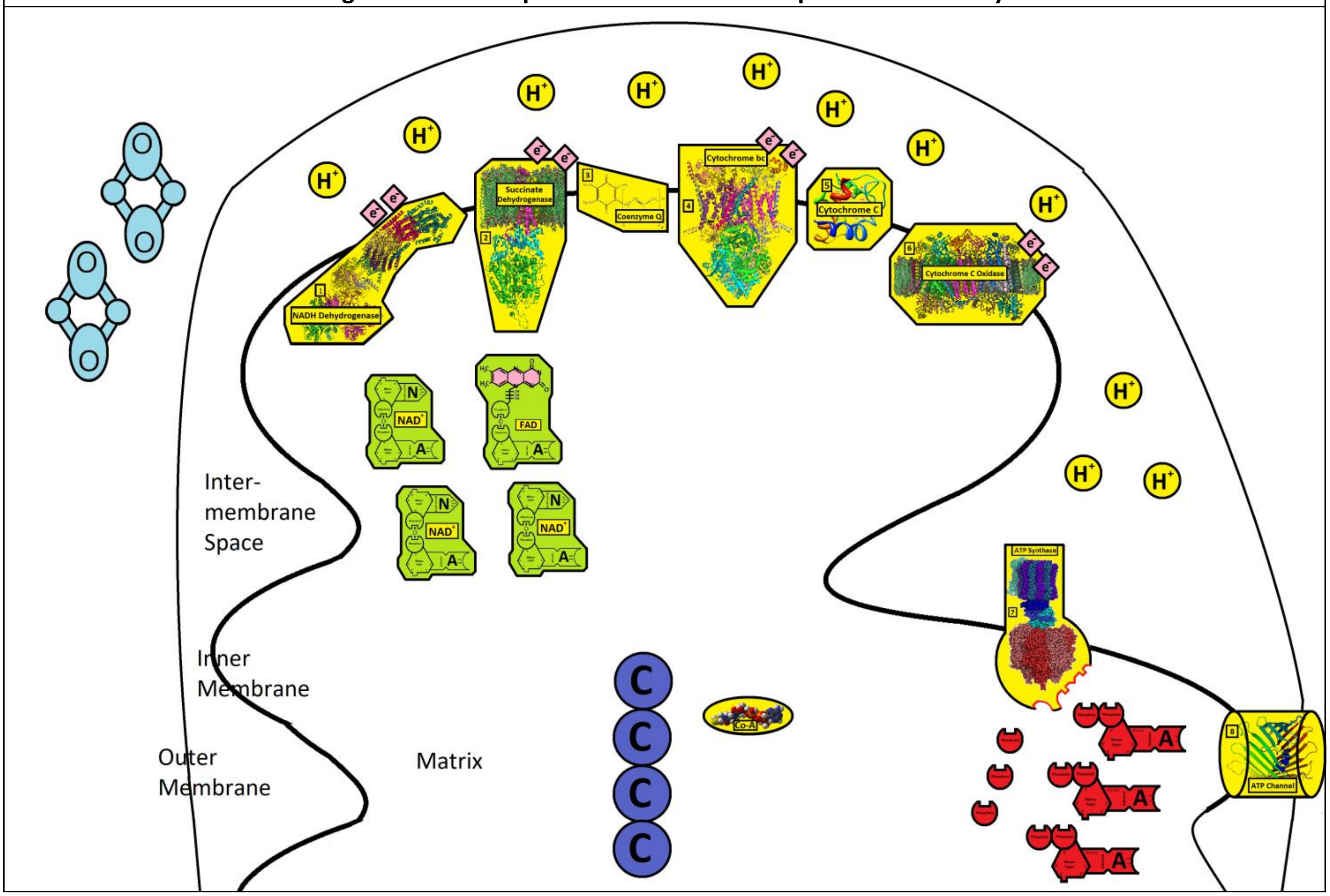
Teacher-Centered Activity (20-40 minutes): This lesson picks up where the breakdown of glucose lesson finished. It would help to review the parts of the mitochondrion and show a diagram of respiration and the chemical equation as seen in a textbook and review what happens in each part of the diagram as the lesson progresses. Start by drawing a large inner and outer mitochondrial membrane and place the respiration magnets on the board as they were at the end of the last lesson, the breakdown of glucose. For this demonstration, add many hydrogen ions to the matrix and intermembrane space. Hydrogen ions are found wherever water occurs (**Figure 3.D.1**).

Figure 3.D.1 – Respiration - Setup of respiration at beginning of electron transport chain



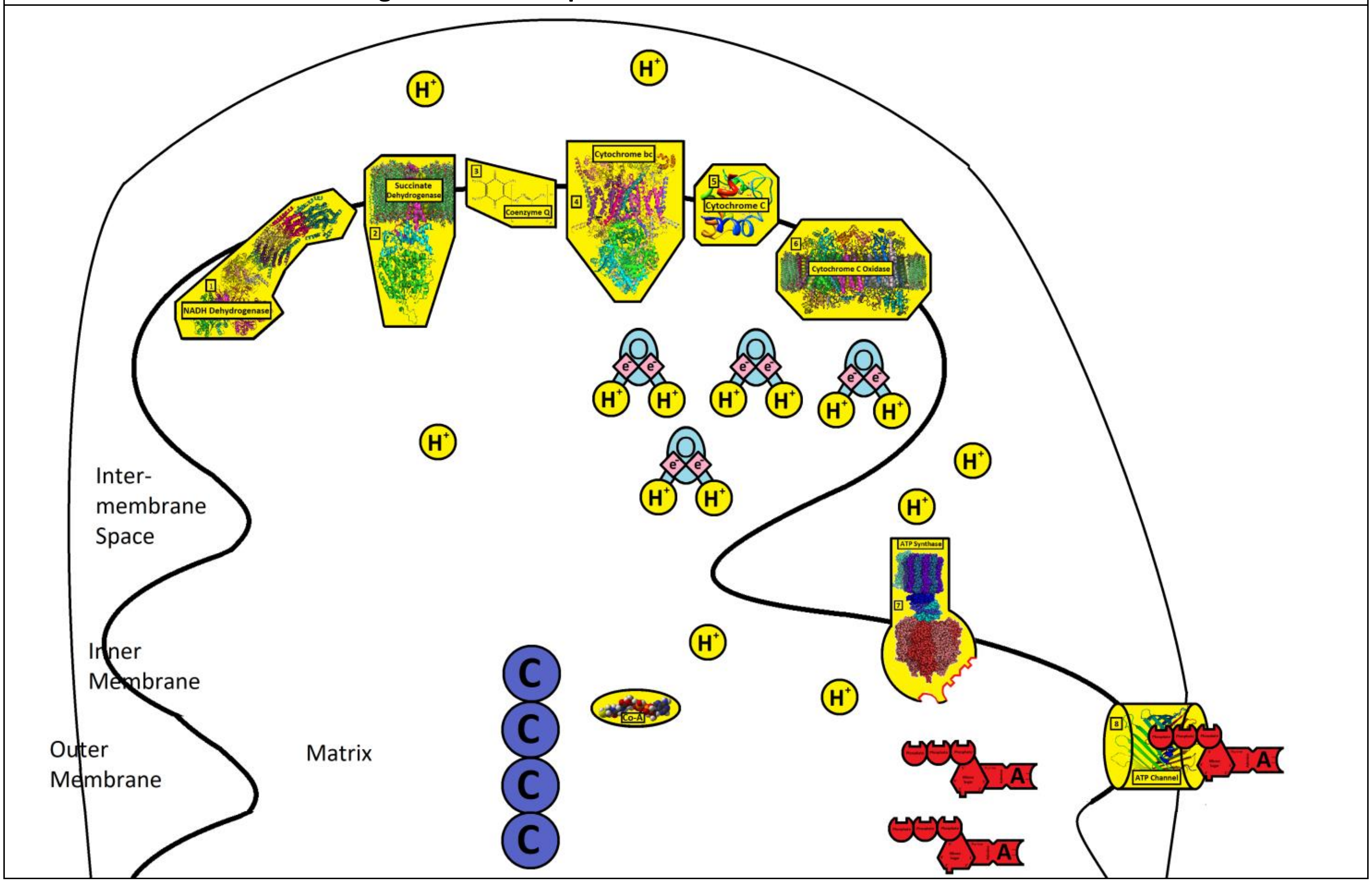
Part 1 - Electron Transport Chain Activity - Start by moving electrons from the NADH molecules onto the first protein in the chain, NADH dehydrogenase. Also remove the hydrogen ions from the NAD and show how they are pumped through the membrane to the intermembrane space by the NADH dehydrogenase protein. FADH2 also drops off electrons at the chain, but this happens at the second protein in the chain, succinate dehydrogenase Move the electrons down the electron transport chain. As the electrons pass cytochrome bc and cytochrome c oxidase, move hydrogen ions out of the membrane to the intermembrane space. Energy from the electrons is used for this proton pumping. This sets up a concentration gradient of H+ ions in the intermembrane space (**Figure 3.D.2**).

Figure 3.D.2 – Respiration - Electron Transport Chain Activity



Part 2 – Formation of ATP and water – The hydrogen ions are in high concentration in the intermembrane space and will move back into the matrix through the ATP synthase protein. When this occurs, ADP and P are put together to make ATP. Demonstrate this with the magnets. The ATP can exit the mitochondrion through the ATP channel protein. Move the hydrogen ions that enter the matrix up to the end of the electron transport chain. When the electrons reach the end of the chain, they will be picked up by the oxygen molecules. Move the oxygen molecules from outside of the mitochondrion to the end of the electron transport chain, and attach the electrons and two hydrogen ions to each oxygen to form water (**Figure 3.D.3**).

Figure 3.D.3 – Respiration - Formation of ATP and water



Student Centered Activity (20-40 minutes): After teaching the electron transport chain and making ATP and water, put students into small groups. A copy of the student guide for the lesson may be given to each group if necessary for guidance. Have the students set up the magnets as seen in **Figure 3.D.1** and take turns moving the magnets and carrying out the processes of the electron transport chain. Allow the students to help one another. Repeat until all students have shown mastery without using the student guide.

Extra exercises – Hypothetical situations: As a group, consider what might happen to the process of the electron transport chain in the following scenarios. Write down and tell/show the teacher the answers when you finish.

1. There is no oxygen available.
2. Cyanide, a poison that is an irreversible enzyme inhibitor of cytochrome C, is present.
3. The ATP synthase protein is mutated so it will not bind ADP but can still transport H^+ ions.
4. There is a large hole in the outer membrane of the mitochondrion.
5. The ATP channel protein is mutated so ATP will not get through.
6. The number of electron transport chains in a mitochondrion is increased.

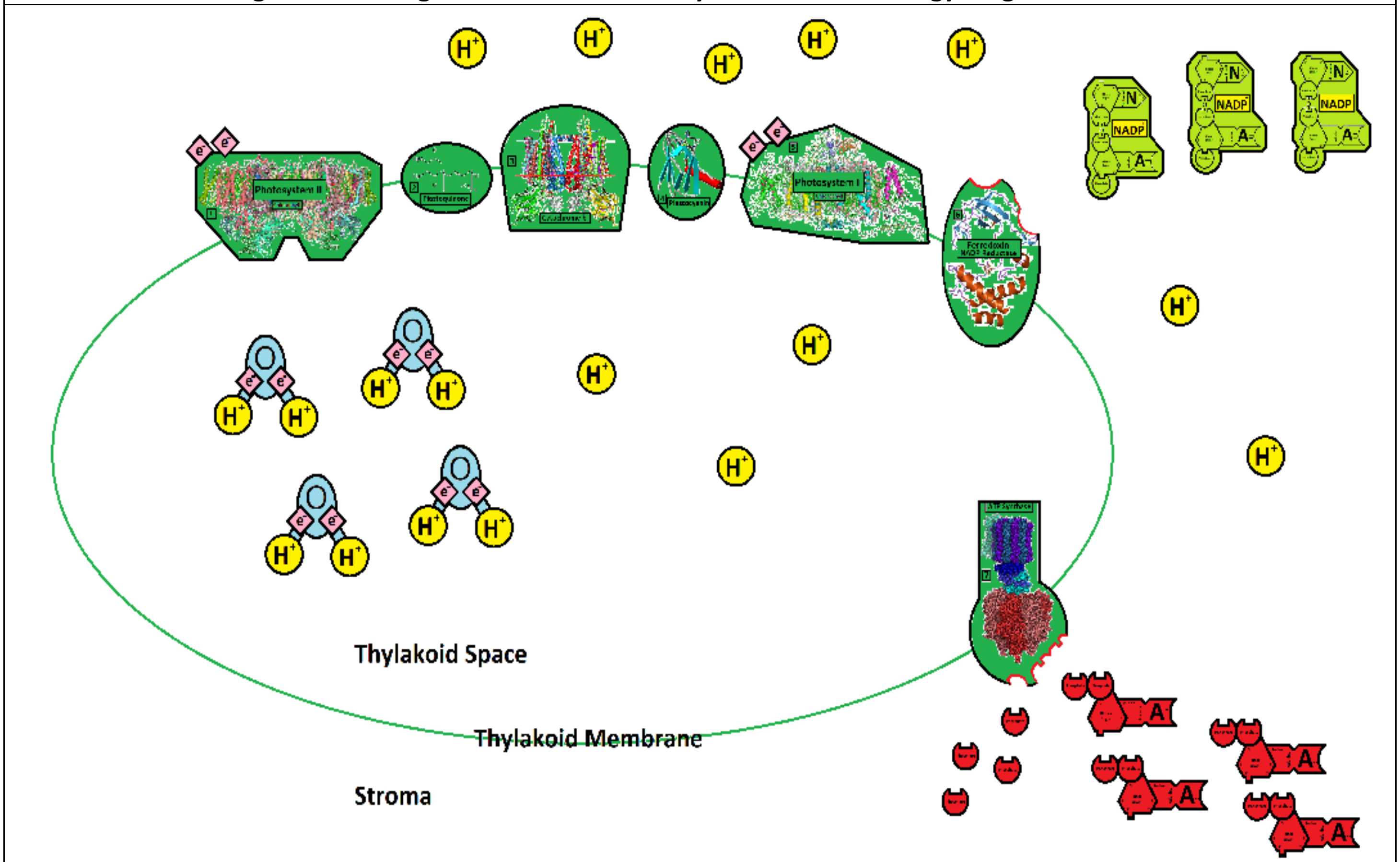
Answers to extra exercises:

1. If no oxygen is available, there will be nothing to accept electrons at the end of the electron transport chain. The chain will back up and NAD will be unable to drop of more electrons at the start of the chain. ATP production will cease. Fermentation will proceed in the cytoplasm and break down the pyruvate into lactic acid or alcohol.
2. Cytochrome C, if inhibited, can no longer transport electrons. No ATP will be produced nor will electrons be accepted by oxygen at the end of the chain.
3. If the ATP synthase is mutated, the electron transport chain will occur, oxygen will be used, and water will be produced. However, no ATP will be made. Hydrogen ions will continue to move through the ATP synthase complex. This would likely result in cell death if all ATP synthase proteins had the same mutation.
4. H^+ ions would leak out through the hole and there would be no concentration gradient established, so no ATP will be produced. Since H+ ions do not move back in through the ATP synthase complex, eventually water would stop forming at the end of the chain.
5. If the ATP channel protein is mutated, ATP will be produced but not be able to escape the mitochondrion. This would likely result in cell death if all channel proteins had the same mutation.
6. If there are more electron transport chains, more ATP can be made by the mitochondrion. The highly folded inner mitochondrial membrane (christae) likely evolved because of this advantage.

Lesson 3A – Light Reactions of Photosynthesis – Student Guide

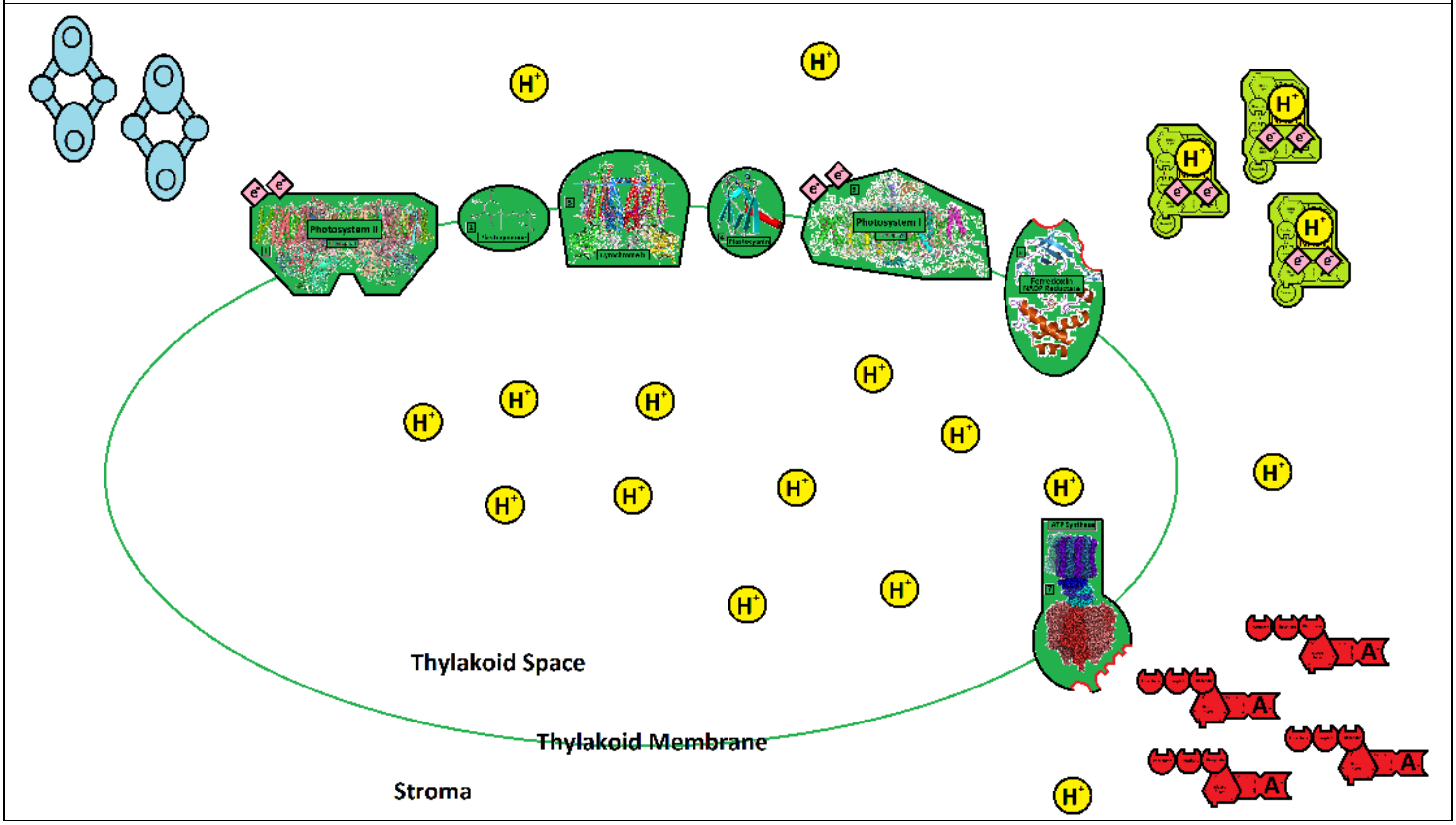
Student Centered Activity: Put all of the magnets on the board and draw an oval for the thylakoid membrane. Place the magnets in the initial position as shown in **Figure 3.A.2** below.

Figure 3.A.2 – Light Reactions of Photosynthesis Initial Biology Magnet Positions



Start the process with sunlight hitting the two photosystems, causing the electrons in the photosystems to move down the electron transport chain. As they move, the plastoquinone and cytochrome complexes use the energy from the electrons to pump hydrogen ions from the stroma into the thylakoid space. As the electrons reach the end of the chain, NADP picks them up in addition to a hydrogen ion, to become NADPH. The electrons that came from the photosystems must be replenished. Photosystem I receives electrons that were moving down the chain that originated in photosystem II, and photosystem II receives electrons from a water molecule located in the thylakoid space, which breaks apart to release hydrogen ions. After this happens twice, two oxygen atoms (from the water molecules) combine to form O_2, which can go through the membrane and exit the cell. A buildup of H^+ ions now exists in the thylakoid space. Those ions will move out through the ATP synthase complex. There are binding sites on the ATP synthase for ADP and P. When the H^+ ions move through, the ATP synthase protein binds ADP and P together to form ATP. At the end of the process, NADPH and ATP have been formed which will be used in the Calvin Cycle to make glucose (**figure 3.A.3**). Each student should practice modeling the process with the Biology Magnets until everyone has shown mastery without using the student guide. Show the process to the teacher or other groups.

Figure 3.A.3 – Light Reactions of Photosynthesis Final Biology Magnet Positions



Extra exercises:

Cyclic Pathway of Photosynthesis – Use the magnets to demonstrate the cyclic pathway of photosynthesis. In the cyclic pathway, only photosystem I produces energized electrons which go to the ferredoxin, then the cytochrome complex, then plastocyanin, and finally back to photosystem 1. The cytochrome complex uses the energy to move hydrogen ions into the thylakoid space, but no water is broken down and no NADPH is produced. ATP is still made as hydrogen ions move through ATP synthase. It is a way ATP can be made by photosynthesis without producing oxygen.

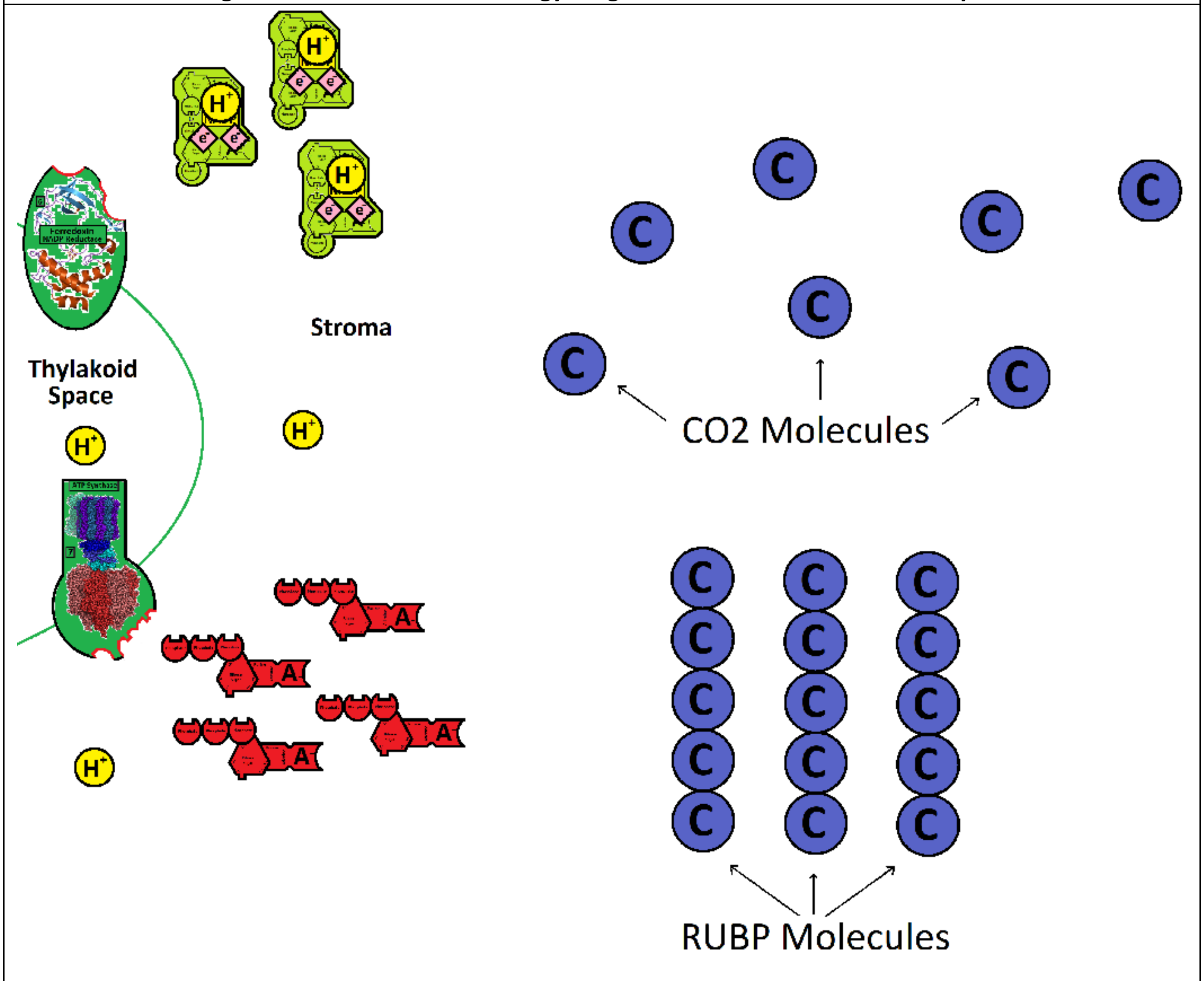
Hypothetical situations: As a group, consider what might happen to the products of the light reactions in the following scenarios. Write down your answers and tell or show your teacher the answers when you finish.

1. The plant is in the dark
2. The ATP synthase protein is mutated so ADP will not bind to it
3. The thylakoid membrane has a hole in it
4. Plastoquinone and/or cytochrome b are mutated so they will move electrons but won't pump hydrogen
5. Magnesium deficiency causes the cell not to be able to make chlorophyll
6. NADP reductase is mutated and will not function

Lesson 3B – Calvin Cycle of Photosynthesis – Student Guide

Student Centered Activity: Each group should set up the magnets on the white board as shown (**Figure 3.B.1)**. Take turns moving the magnets and carrying out the processes of the Calvin cycle as was explained to you by the teacher.

Figure 3.B.1 – Position of Biology Magnets at the start of the Calvin cycle



First, demonstrate carbon fixation by attaching three of the CO2 carbon atoms to the RUBP molecules using the Rubisco enzyme. This forms three 6-carbon compounds that immediately break down into six 3-carbon compounds known as phosphoglycerate (PGA). Pull the 6-carbon compounds apart into 3-carbon compounds. (**Figure 3.B.2**). In the reduction portion of the reaction, ATP and then NADPH act upon the PGA to donate phosphates, electrons, and hydrogen ions to the PGA to form 6 molecules of glyceraldehyde 3-phosphate (G3P). Demonstrate this by using the ATP and NADPH formed in the light reactions to transfer the magnets to the PGAs. (**Figure 3.B.3**). One of the G3P molecules gets stored away and the other 5 are used for the regeneration of RUBP phase, again by using ATP from the light reactions. Demonstrate this with the molecules by putting aside a G3P and rearranging the rest of the carbon magnets back to the original RUBP structure. The ADP molecules and the NADP molecules return to the light reactions to be recycled. Complete the process again and there will be two G3P molecules stored away. The two G3P molecules lose their phosphate groups and bind together to form glucose (**Figure 3.B.4**). The glucose molecule starts the respiration lesson.

Figure 3.B.2 – Carbon Fixation Process

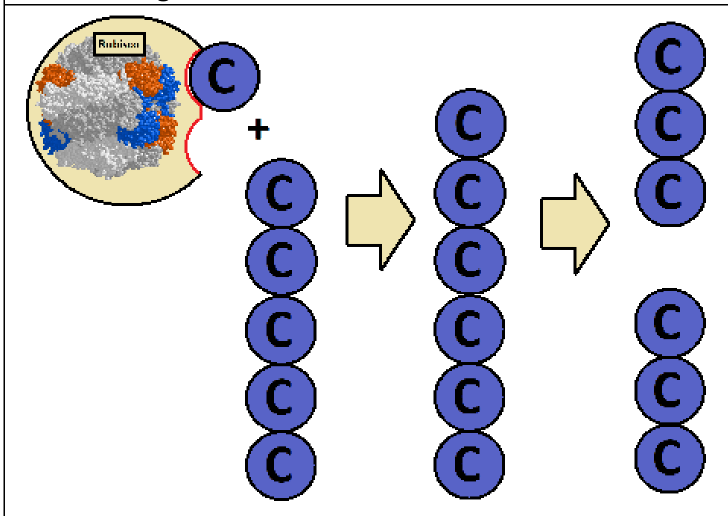


Figure 3.B.3 – Reduction Process

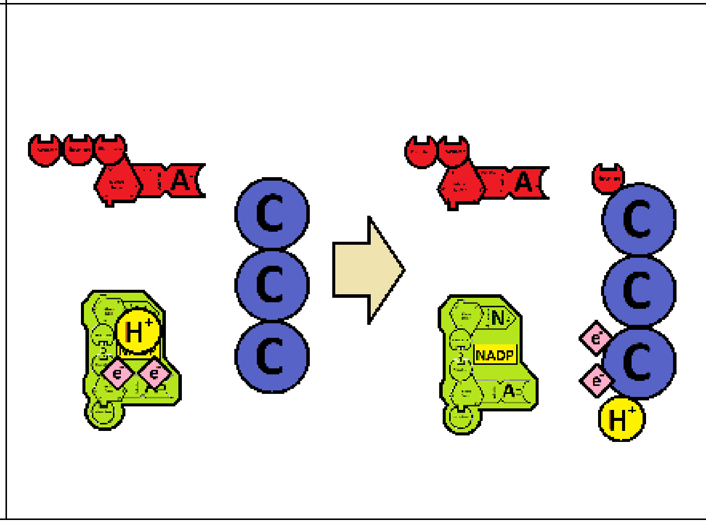
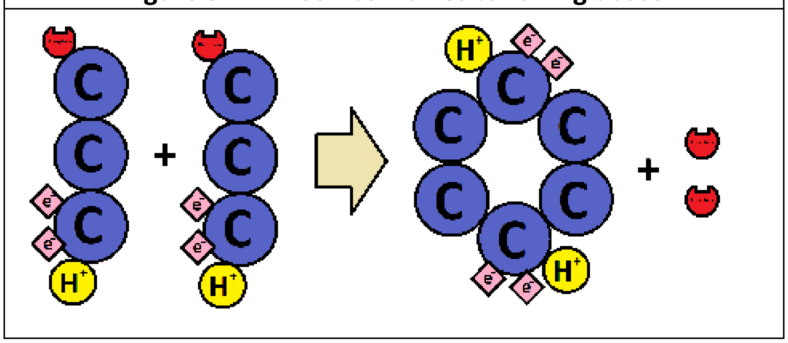


Figure 3.B.4 – G3P combines to form glucose



Practice all of the steps above until all students have shown mastery without using the student guide. Demonstrate what you have learned to the teacher or to other groups.

Extra exercises: C3 vs. C4 photosynthesis – Use the magnets to represent C4 photosynthesis. First draw a box on the board next to the area where the Calvin cycle occurs which will represent the mesophyll cell. Use one of the 3-carbon group magnets to represent phosphoenolpyruvate (PEP) in the mesophyll cells, which binds CO2 to make a 4-carbon molecule called oxaloacetic acid (OAA). The 4-carbon compound is then transported to bundle sheath cells to release the CO2 for use in the Calvin Cycle.

Hypothetical Situations:

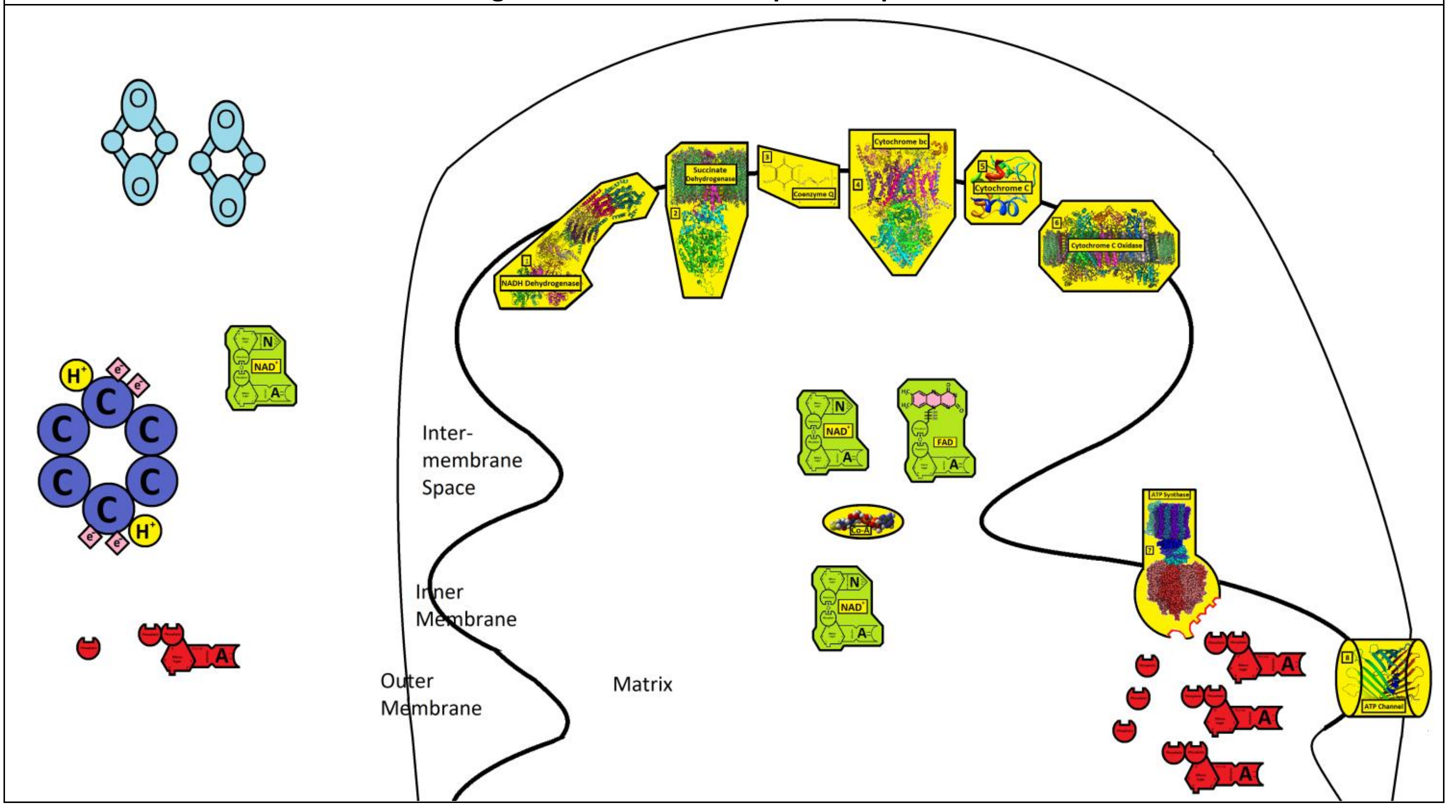
As a group, consider what might happen to the process of the Calvin cycle in the following scenarios. Discuss the scenarios then write down the answers and tell/show the teacher the answers when finished.

1. The plant is in the dark.
2. The Rubisco protein is mutated so it cannot attach to CO_2.
3. There is are low levels of RUBP in the stroma.
4. There is NADPH but no ATP.
5. Stomates in the leaves are closed lowering the levels of CO_2.
6. Due to burning of fossil fuels, there are higher levels of CO_2.

Lesson 3C – Respiration and the Breakdown of Glucose – Student Guide

Student Centered Activity: Start by drawing a large inner and outer mitochondrial membrane and place the respiration magnets on the board, with a glucose molecule outside of the mitochondrion (**Figure 3.C.1**).

Figure 3.C.1 – Initial Setup for Respiration



Part 1 - Glycolysis - Glycolysis occurs in the cytoplasm outside of the mitochondrion. First, break the glucose apart to form two 3-carbon molecules called pyruvate. Move electrons and a hydrogen ion from the glucose to an NAD to form NADH, and put together ADP + P to form ATP. Move the NADH into the mitochondrion to the electron transport chain (**Figure 3.C.2**).

Part 2 – Preparatory Reaction – Move a pyruvate molecule into the matrix of the mitochondrion and have it attach to the Co-A (coenzyme A) magnet. Remove a carbon atom from the structure and have it leave the mitochondrion. That carbon represents CO_2 released by respiration. Form NADH by moving electrons and a hydrogen ion from the pyruvate to the NAD^+. The new molecule formed is acetyl-CoA (**Figure 3.C.3**).

Figure 3.C.2 – Glycolysis

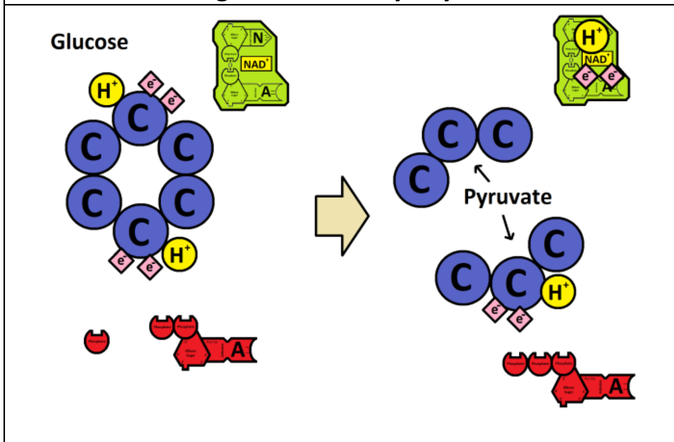
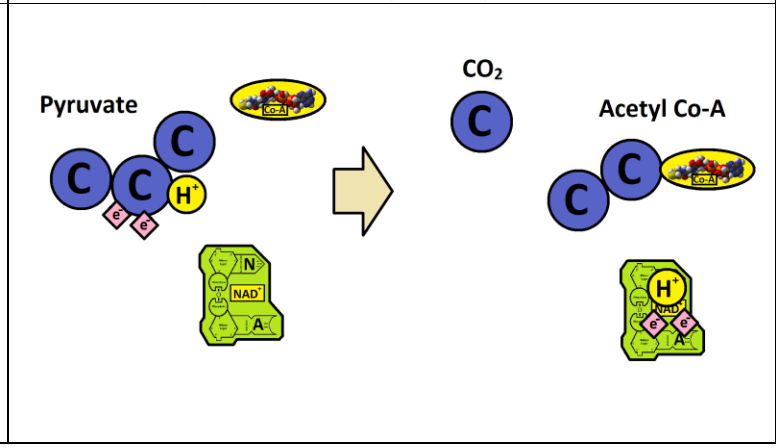
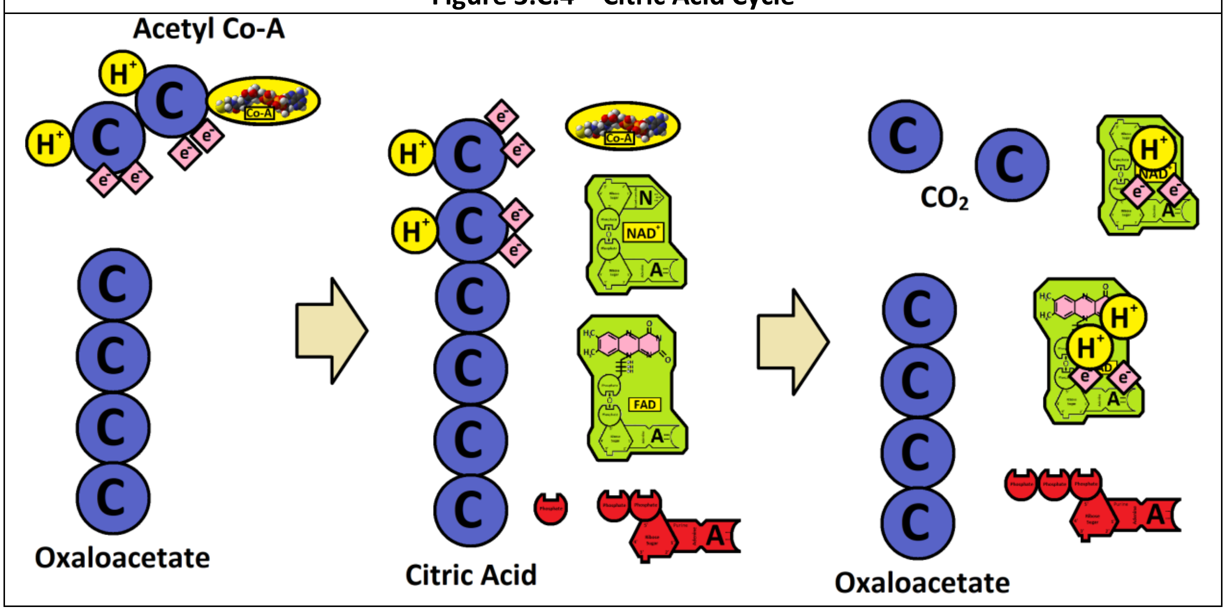


Figure 3.C.3 – Preparatory Reaction



Part 3 – Citric Acid Cycle – The Citric Acid Cycle also happens in the matrix of the mitochondrion. First, add more electrons and hydrogens to the acetyl-CoA molecule. These were always present in the glucose. Attach the acetyl group to the 4-carbon oxaloacetate molecule, releasing the CoA. This forms citric acid. Break down citric acid by removing carbon atoms one at a time from the end. These carbon atoms exit the mitochondrion as carbon dioxide. Move electrons and hydrogen ions to NAD^+ and FAD to form NADH and $FADH_2$. Also put together ATP here as well. The 4-carbon oxaloacetate remains at the end of the cycle. The original glucose has been completely broken down into CO_2 atoms, ATPs, and several electron carriers (NADH, $FADH_2$). The electron carriers will be used to start the electron transport chain in the next lesson (**Figure 3.C.4**). Each student in the group should repeat all three parts of the process until it can be done without looking at the student handout. When finished, demonstrate to the teacher or to other groups.

Figure 3.C.4 – Citric Acid Cycle

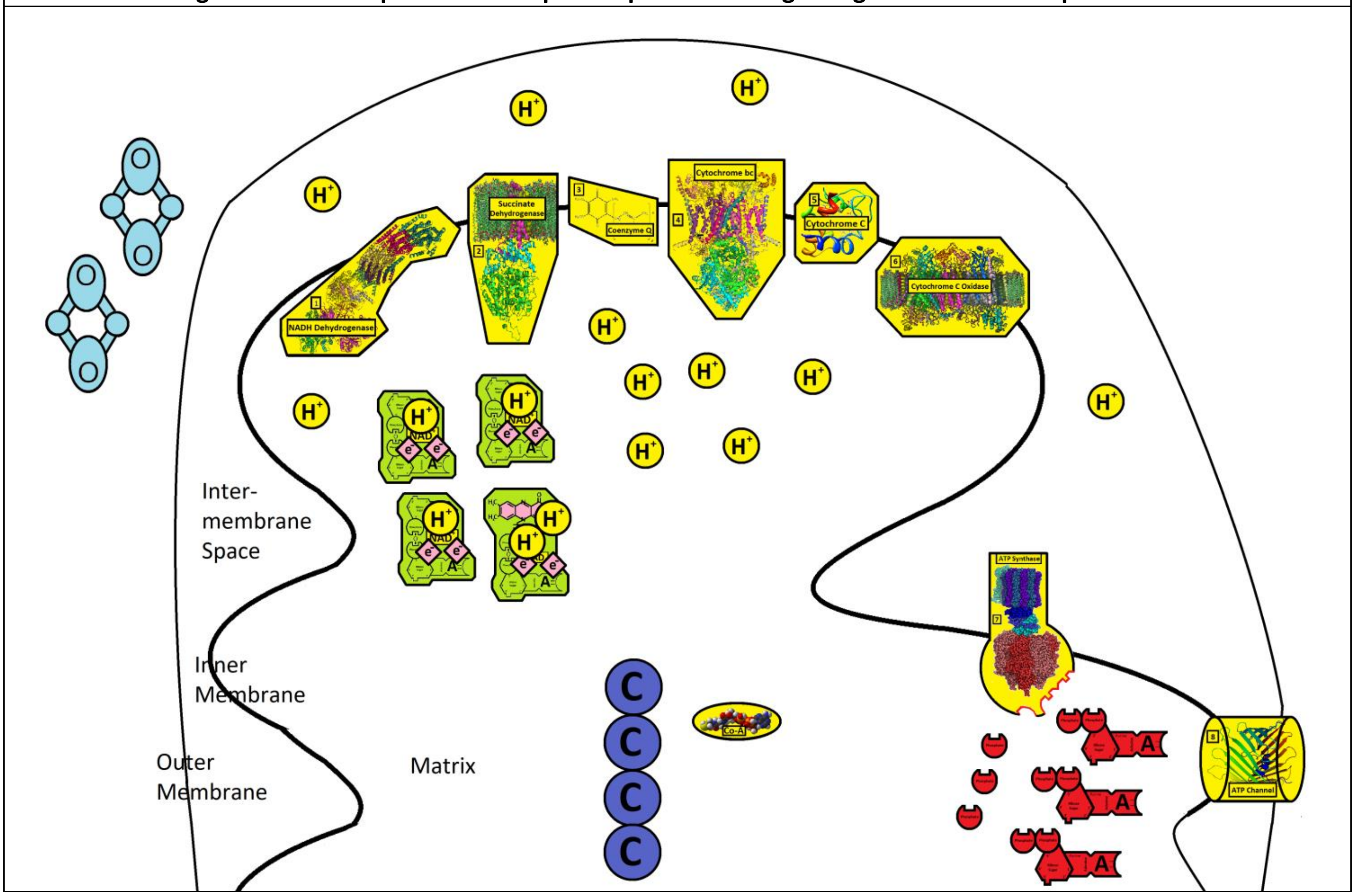


Extra exercise: Fermentation – After glycolysis, demonstrate fermentation by having the pyruvate take back hydrogens and electrons from NADH in the cytoplasm instead of taking them to the mitochondrion. To show alcoholic fermentation in plants, remove a carbon atom from the pyruvate and release it, leaving a two-carbon alcohol (ethanol) molecule. The extra carbon represents the CO_2 released in alcoholic fermentation.

Lesson 3D – Respiration and the Electron Transport Chain in the Mitochondrion – Student Guide

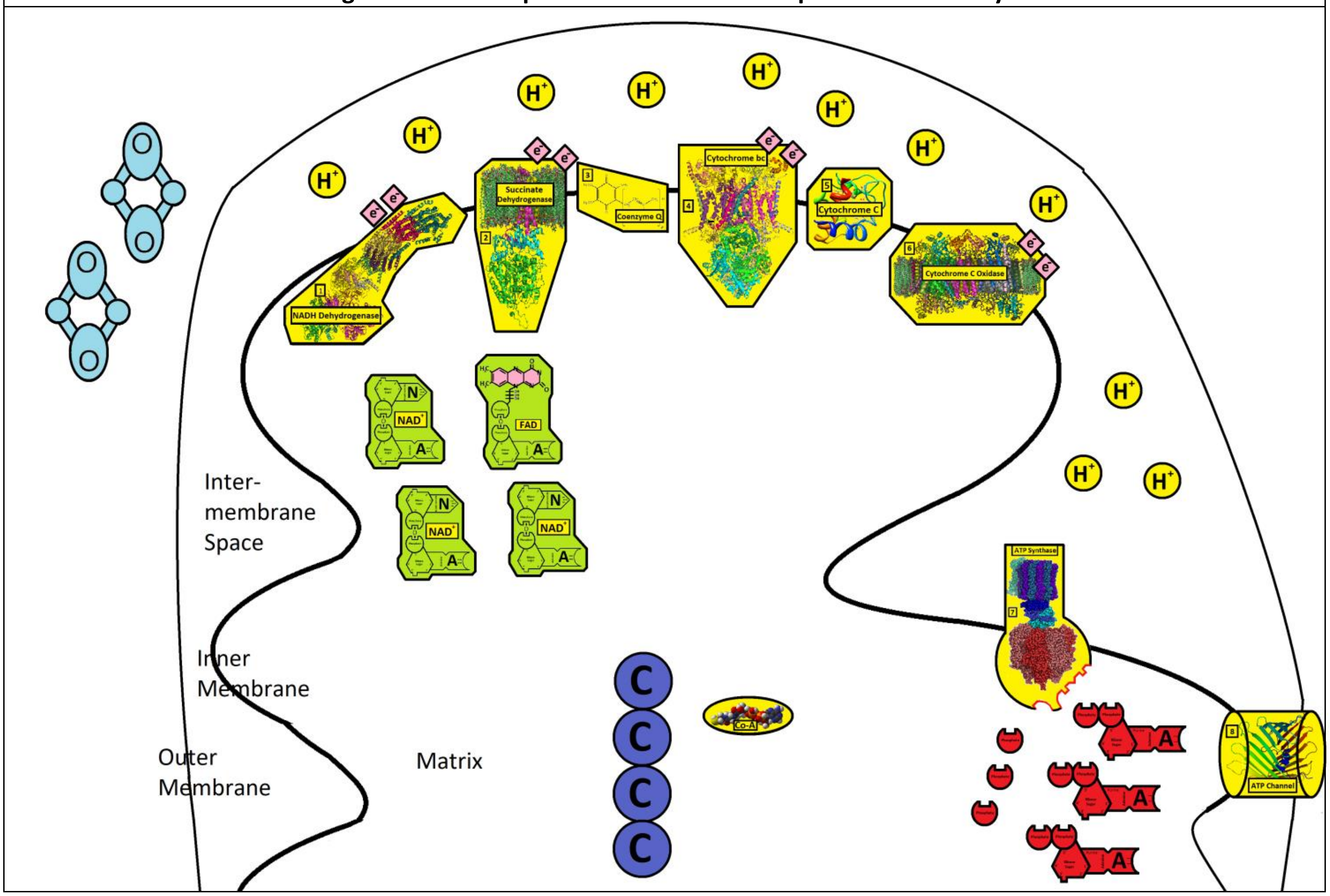
Student Centered Activity: Start by drawing a large inner and outer mitochondrial membrane and place the respiration magnets on the board where the last lesson (Breakdown of Glucose) left off, while adding many hydrogen ions to the matrix and intermembrane space. Hydrogen ions are found wherever water occurs (**Figure 3.D.1**).

Figure 3.D.1 – Respiration - Setup of respiration at beginning of electron transport chain



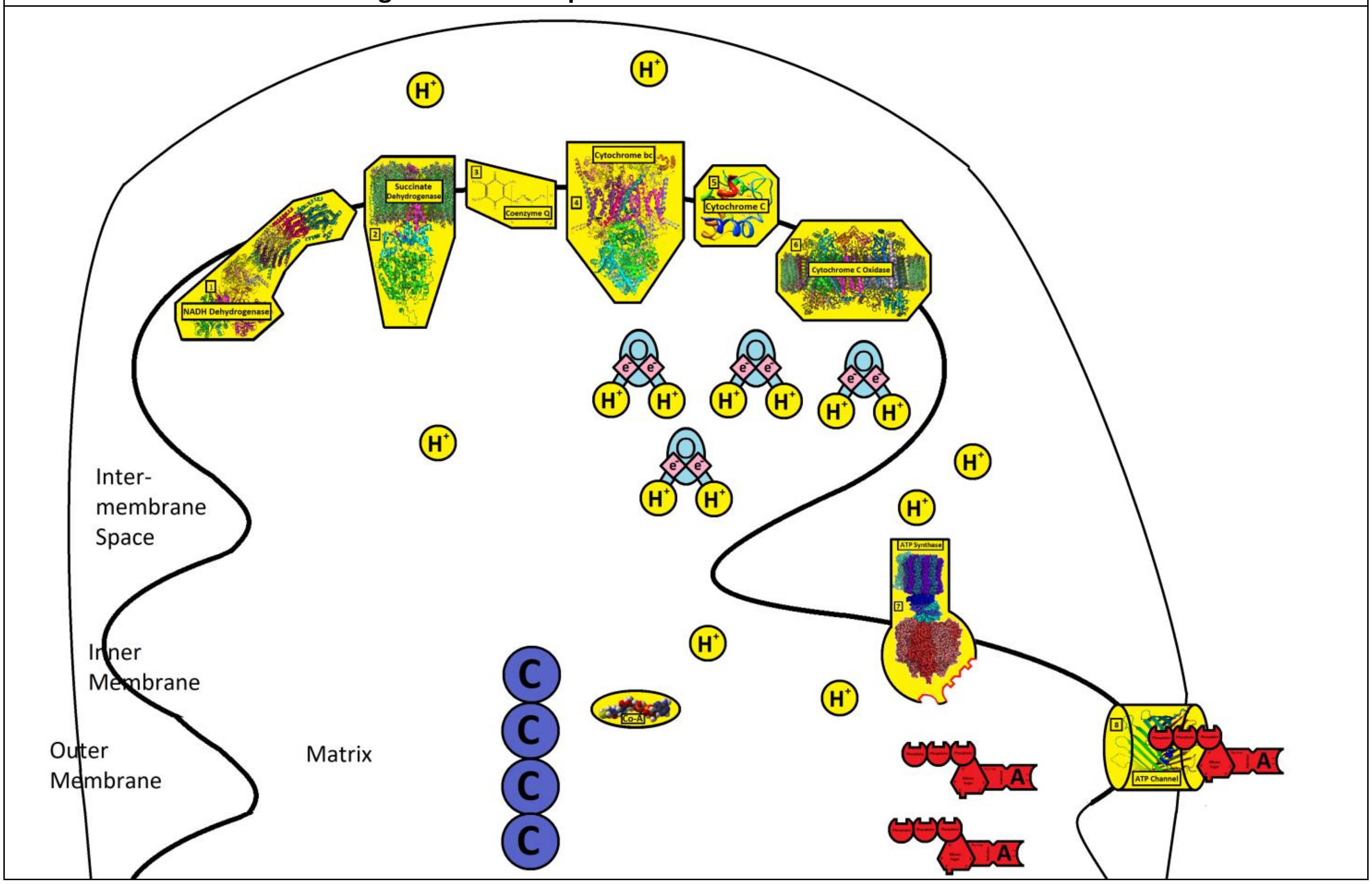
Part 1 - Electron Transport Chain Activity - Start by moving electrons from the NADH molecules onto the first protein in the chain, NADH dehydrogenase. Remove the hydrogen ions from the NAD^+ and show how they are pumped through the membrane to the intermembrane space by the NADH dehydrogenase protein. $FADH_2$ also drops off electrons at the chain, but this happens at the second protein in the chain, succinate dehydrogenase. Move the electrons down the electron transport chain. As the electrons pass the cytochrome bc protein and the cytochrome c oxidase protein, move hydrogen ions out of the membrane to the intermembrane space. Energy from the electrons is used for this proton pumping. This sets up a concentration gradient of H^+ ions in the intermembrane space (**Figure 3.D.2**).

Figure 3.D.2 – Respiration - Electron Transport Chain Activity



Part 2 – Formation of ATP and water – The hydrogen ions are in high concentration in the intermembrane space. Move the H^+ ions back into the matrix through the ATP synthase protein. When this occurs, put together ADP and P to make ATP. Move the ATP through the ATP channel protein to exit the mitochondrion. Move the hydrogen ions that enter the matrix up to the end of the electron transport chain. Move the oxygen molecules to the end of the chain to pick up the electrons and attach two hydrogen ions to each oxygen to form water (**Figure 3.D.3**).

Figure 3.D.3 – Respiration - Formation of ATP and water



Extra exercises: As a group, consider what might happen to the process of the electron transport chain in the following scenarios. Write down your answers and tell/show your teacher the answers when you finish.

1. There is no oxygen available.
2. Cyanide, a poison that is an irreversible enzyme inhibitor of cytochrome C, is present.
3. The ATP synthase protein is mutated so it will not bind ADP but can still transport H^+ ions.
4. There is a large hole in the outer membrane of the mitochondrion.
5. The ATP channel protein is mutated so ATP will not get through.
6. The number of electron transport chains in a mitochondrion is increased.