Photosynthesis

Aim: The aim of my investigation was to determine how limiting factors would affect the rate of photosynthesis in a plant.

It all begins at the bottom of the food chain with green plants being the producers. All the food in the world is made by plants; they use energy in sunlight to make food. This process is called *photosynthesis*. Plants need two chemicals to make this food- one is *water* which they get from the soil. The other is *carbon dioxide* which thy get from the air. They also need *sunlight energy* which is used to make the water and carbon dioxide *react* together. Water and carbon dioxide are *ignorant substances* (not made by living things). They usually have molecules. These three things are sometimes called *raw materials*. The reaction between the two chemicals (using sunlight) produces two new substances– glucose and water. Glucose is an *organic substance* (made by all living things) which usually have large molecules. The energy you get from glucose was once sunlight energy and somewhere in the world a plant converted it into *chemical energy* which your body can now use. Plants are living *food factories*.
The *production* of glucose and oxygen can be written as a word equation;

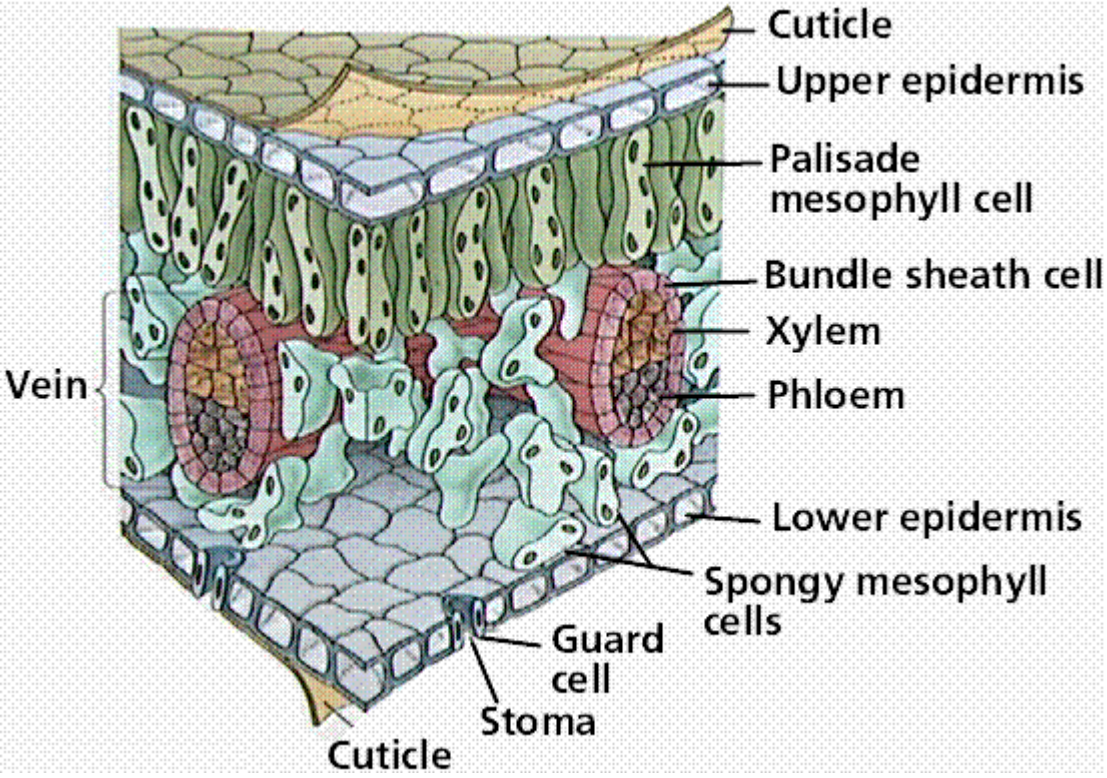
$$\text{WATER + CARBON DIOXIDE} \xrightarrow[\text{ENERGY}]{\text{SUNLIGHT}} \text{GLUCOSE + OXYGEN}$$

The balanced molecular equation for this is;

$$6H_2O\,(1) + 6CO_2\,(G) \xrightarrow[\text{ENERGY}]{\text{SUNLIGHT}} C_6H_{12}O_6\,(AQ) + 6O_2\,(G)$$

All plants are green, the green color is *chlorophyll*. It is a very important substance, without it photosynthesis couldn't happen. Chlorophyll is a complex molecule which is imbedded in the *thylakoids membrane* which absorbs light. The thylakoids membrane is found in the chloroplasts. These molecules are the most important pigments for absorbing the light energy used in photosynthesis. A chlorophyll molecule has a *hydrophobic* 'tail' that embeds the molecule into the thylakoid membrane. The hydrophobic tail is made up of carbon, hydrogen and oxygen based molecules. The 'head' of a chlorophyll molecule is ring called *porphyrin*. The porphyrin ring of chlorophyll, which has a magnesium atom at its center, is the part of a chlorophyll membrane that absorbs light energy. This energy is used to make carbon dioxide react with water to make glucose.

Chlorophyll is found in chloroplasts which are double membrane bound organelles which enclose additional membranes called thylakoids. The disc shaped thylakoids posses an interior space. The thylakoids are stacked to form *grana*, which are suspended in the *stroma* of the chloroplasts. Chloroplasts are found in most plant cell. Most photosynthesis happens in leaves but other parts of plants above ground can photosynthesize. Stems may contain chloroplasts and so can things like peapods. If it contains chloroplasts then it can photosynthesize.



Leaves are very thin, yet they are made up of many layers. The cells which contain chloroplasts and photosynthesize are in the middle layers. These layers are called the *mesophyll layer which means* 'middle leaf'. A mesophyll is a *parenchyma tissue*. It is a true *assimilation tissue*. Assimilation tissues are all those tissues that are made from chloroplast-containing cells and are thus able to perform photosynthesis. They are found in all green parts of a plant. An important aspect of photosynthesis is the integration of carbon dioxide into organic compounds. The resulting products are summed up as *assimilates*. Mesophyll is in the leaves of most ferns and phanerogams; it is organized into *palisade parenchyma* and *spongy parenchyma*. The typical leaf is of a *dorsiventral* structure. The palisade parenchyma is usually directly beneath the epidermis of the upper surface of the leaf. The spongy parenchyma fills the space beneath the palisade parenchyma. It is interspersed with a voluminous intercellular system, whose cavities are in direct contact with the atmosphere via the *stomata.*

The cells of the palisade parenchyma are cylindrical and contain three to five as many chloroplasts as those of the spongy parenchyma. The chloroplasts stay usually near the cells wall, since this adjustment guarantees optimal use of light. The development and particularly the differentiation of the palisade parenchyma are influenced by external factors like light and the CO_2 content of the atmosphere. In many species, it is distinguished between sun and shade leaves. *Sun leaves* have been exposed to large quantities of light during ontogenesis. This results in a multilayered palisade parenchyma. *Shade leaves* in contrast perceive only a little light, the palisade parenchyma stays single layered. The enlargement of the palisade parenchyma causes usually a reduction of the spongy parenchyma, which is accordingly less well developed in sun leaves. As important as the exposition to light is the leaf's position at the stem. Old leaves that live near the soil do

often have a palisade parenchyma of just one layers thickness, while younger ones at the top of the plant have normally multi-layered palisade parenchyma's.

The variability of the cells of the spongy parenchyma and that of its organization is even greater than that of the palisade parenchyma. It is often said to be an *aerenchyma,* since it is characterized by a large number of connected intercellular spaces. This does not mean that the contact between palisade parenchyma and intercellular spaces is less well developed. On the other hand the proportion of palisade parenchyma that is in contact with the intercellular space is larger than that of the spongy parenchyma. The elongated and cylindrical shape of the cells enables only selective contact to neighboring cells even at close packing. The spongy parenchyma shows larger contact areas as well as cell-to-cell contacts between palisade parenchyma and spongy parenchyma and between spongy parenchyma and cells of the vascular bundles. This is also the reason why water and assimilate transport proceeds without losses.

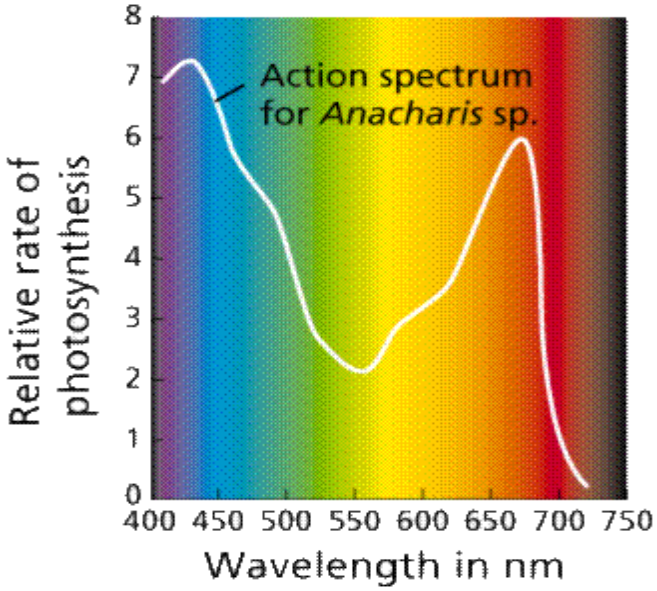
The other two layers in the leaf are the protective layers on the top and bottom called the *epidermis.* The cells in the epidermis make a waxy substance which spreads out over the leaf called the *cuticle.* The lower epidermis has holes (stomata) in it which open directly into the inside of the leaf. They are very small but can be seen through a microscope. Each *stoma* has a pair of special cells surrounding it, called *guard cells* which can open or close the stomata. In light the guard cells swell, causing the pore to be at its widest and CO_2 diffuses into the leaf and into the cells to be assimilated in photosynthesis. In the dark or under drought conditions the guard cells are not turgid, the stomata are closed and no photosynthesis takes place. Opening of the stomata not only allows CO_2 to diffuse into the leaf, but allows water to diffuse out of the leaf. The alteration in the size of the stomata occurs in response to a variety of the external stimuli such as light, carbon dioxide concentration and water.

The main food producing part of the leaf is the palisade layer. The *raw materials* for photosynthesis must be delivered to the cells in the palisade parenchyma as swiftly as possible. Carbon dioxide gets into the leaf through the stomata. A very small part of the air -0.04%- is carbon dioxide which diffuses through the open stomata into the spongy parenchyma. As the leaf is so thin, it quickly diffuses all the way to the chloroplasts in the palisade parenchyma.

Water is brought to the leaf in tubes called *xylem vessels.* These are very long tubes which run all the way up from the roots of the plants through its stem and into the leaves. The veins of a leaf contain xylem vessels. Branches of xylem vessels run closely to every part of a leaf so each palisade cell is provided with a constant supply of water. The carbon dioxide and water enter the chloroplasts in the palisade cells where chlorophyll is absorbing sunlight. The carbon dioxide and water react together. Glucose and oxygen is created.

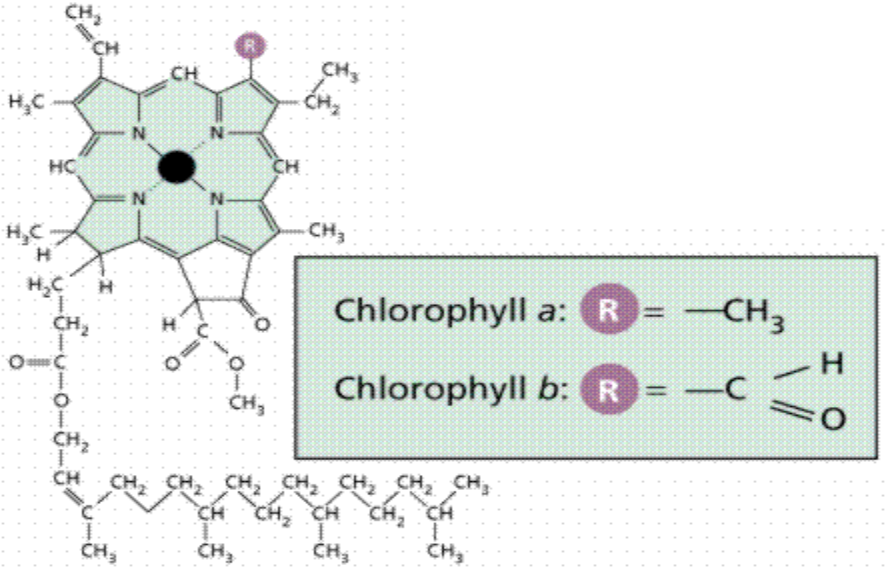
White light is separated into different colours (wavelengths) of light by passing through a prism. Wavelength is defined as the distance from peak to peak. The energy is inversely proportional to the wavelength: longer wavelengths have less energy than shorter ones. Visible light is one small part of the electromagnetic spectrum. The longer the wavelength of visible light, the more red the color. Likewise the shorter wavelengths are towards the violet side of the spectrum. Wavelengths longer than red are referred to as infrared, while those shorter than violet are ultraviolet. Chlorophyll cannot absorb all the different wavelengths in the sunlight which hits it. The pigment molecules in photosynthetic organisms absorb specific wavelengths of light. It can absorb red and blue light but cannot absorb green light. This is why chlorophyll is green. All the green light

which hits it is reflected from it, or passes through it. Some plants, such as copper beach trees or red seaweed do not look green. They do have chlorophyll which reflects green light. Just as in other plants. But copper beach trees and red seaweed also contain other pigments which absorb green light and reflect red light. The mixture of green light from the chlorophyll, and red light from these other pigments, looks to us like a reddish brown color. The action spectrum of photosynthesis is the relative effectiveness of different wavelengths of light at generating electrons.

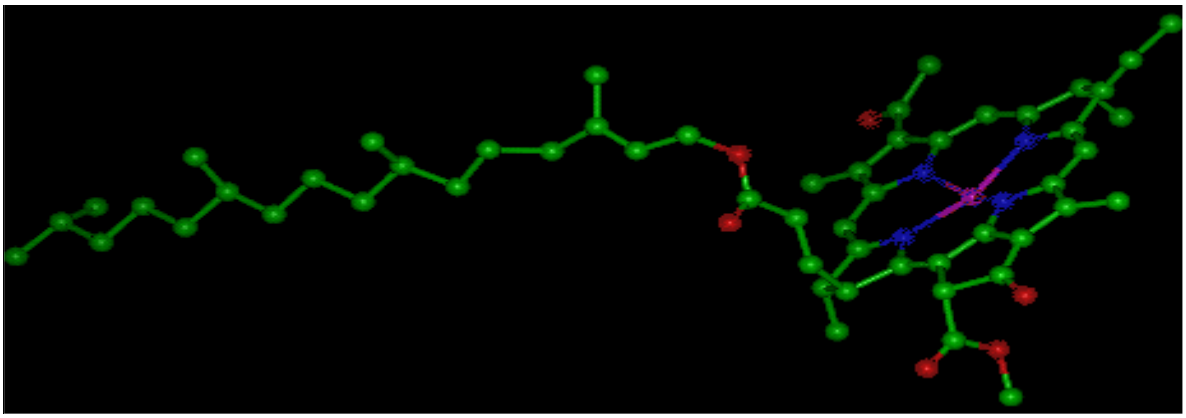


Action spectrum of elodea Images from Purves et al., Life: The Science of Biology, 4th Edition.

If a pigment absorbs light energy, one of three things will occur. Energy is dissipated as heat. The energy may be emitted immediately as a longer wavelength, a phenomenon known as fluorescence. Energy may trigger a chemical reaction, as in photosynthesis. Chlorophyll only triggers a chemical reaction when it is associated with proteins embedded in a membrane (as in a chloroplast) or the membrane infoldings found in photosynthetic prokaryotes such as cyanobacteria and prochlorobacteria.

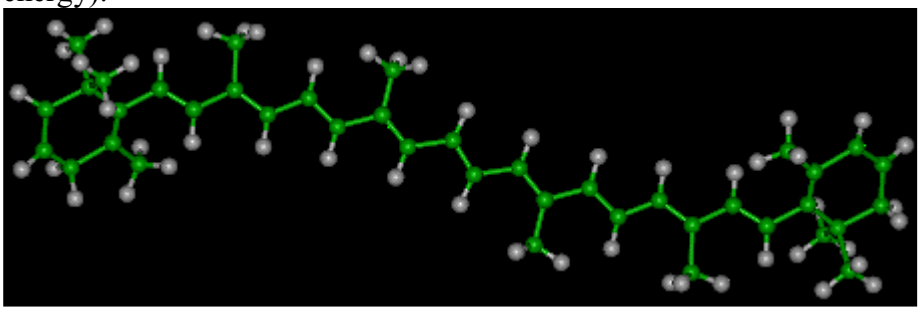


Chlorophyll is a complex molecule. Several modifications of chlorophyll occur among plants and other photosynthetic organisms. All photosynthetic organisms (plants, certain protstians, prochlorobacteria and cyanobacteria) have *chlorophyll a.*



Molecular model of chlorophyll. *www.nyu.edu:80/pages/mathmol/library/photo*

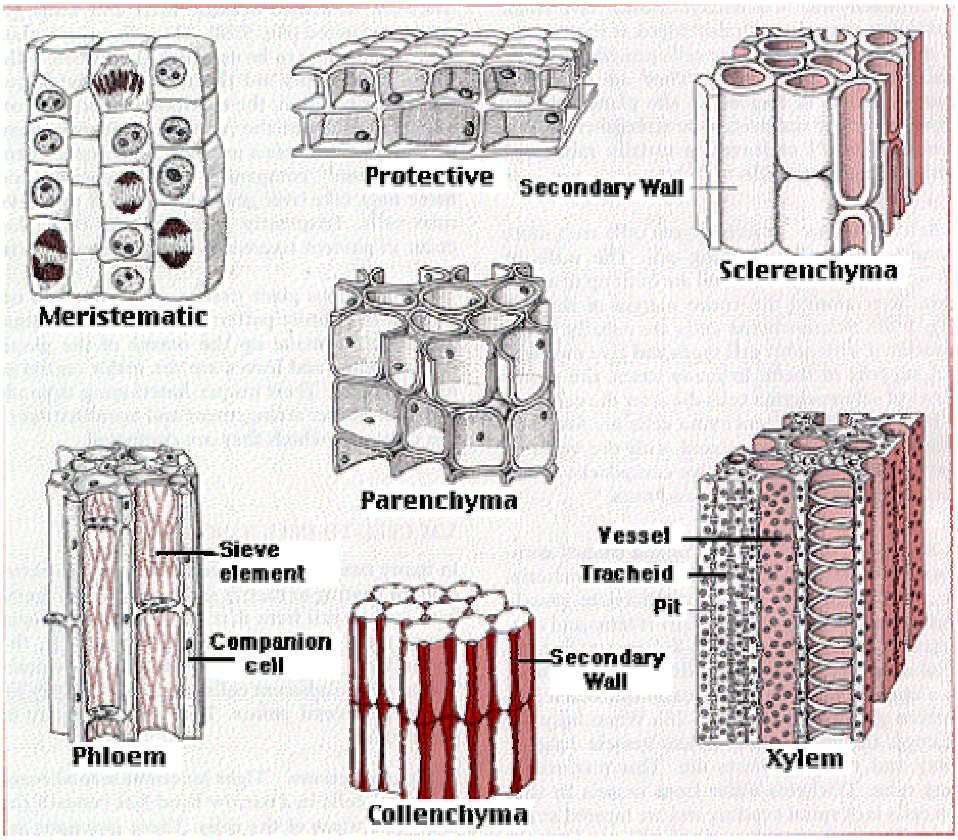
Accessory pigments absorb energy that chlorophyll a doesn't absorb. Accessory pigments include *chlorophyll b* (also c, d and e in algae and protistians), xanthophylls and carotenoids. Chlorophyll a absorbs its energy from the violet-blue and reddish orange-red wavelengths, and a little from the intermediate (green-yellow-orange) wavelengths. Caroteniods and chlorophyll b absorb some of the energy in the green wavelength. Both chlorophylls also absorb in the orange-red end of the spectrum (with longer wavelengths and lower energy).



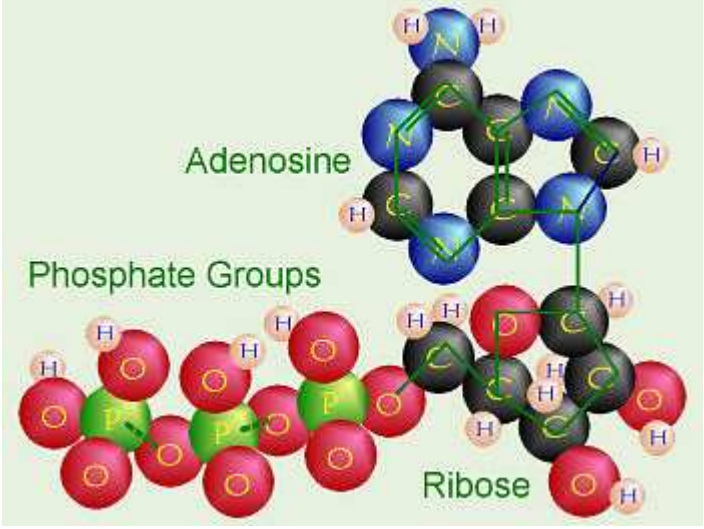
Molecular model of carotene. *http://www.nyu.edu:80/pages/mathmol/library/photo.*

A mature vascular plant contains several differentiated cell types. These are grouped together in tissues. Some tissues contain only one type of cell. Some consist of several. Meristematic: The main function of meristematic tissue is mitosis. The cells are small, thin-walled, with no central vacuole and no specialized features. It is located in a ring of meristematic tissue, called the *cambium* that is found within the mature stem. The cells produced in the meristems soon become differentiated into one or another of several types. Protective: protective tissue covers the surface of leaves and the living cells of roots and stems. Its cells are flattened with their top and bottom surfaces parallel. The upper and lower epidermises of the leaf are examples of protective tissue.
Parenchyma: the cells of parenchyma are large, thin-walled, and usually have a large central vacuole. They are often partially separated from each other. They are usually stuffed with plastids. In areas not exposed to light, colorless plastids predominate and food storage is the

main function. The cells of the white potato are parenchyma cells. Where light is present chloroplasts predominate and photosynthesis is the main function.
Sclerenchyma: The walls of these cells are very thick and built up in a uniform layer around the entire margin of the cell. Often, the protoplasts die after the cell wall is fully formed. The cells are usually found associated with other cells types and give them mechanical support. Sclerenchyma is found in stems and also in leaf veins. It also makes up the hard outer covering of seeds and nuts.
Collenchyma: the cells have thick walls that are especially thick at their corners. These cells provide mechanical support for the plant. They are most often found in areas that are growing rapidly and need to be strengthened. The petiole (stalk) of leaves is usually reinforced with Collenchyma.
Xylem: conducts water and dissolved minerals from the roots to all the other parts of the plant. In angiosperms, most of the water travels in the xylem vessels. These are thick-walled tubes that can extend vertically through several feet of xylem tissue. Their diameter may be as large as 0.7 mm. Their walls are thickened with secondary deposits of cellulose and are usually further strengthened by impregnation with lignin. The secondary walls of the xylem vessels are deposited in spirals and rings and are usually perforated by pits. Xylem vessels arise from individual cylindrical cells oriented end to end. At maturity the end walls of these cells dissolve away and the cytoplasmic contents die. The result is the xylem vessel, a continuous nonliving duct. The vessels carry water and some dissolved solutes, such as inorganic ions, up the plant. Xylem also contains tracheids. These are individual cells tapered at each end so the tapered end of one cell overlaps that of the adjacent cell. Like xylem vessels, they have thick, lignified walls and, at maturity, no cytoplasm. Their walls are perforated so that water can flow from one tracheid to the next. The xylem of ferns and conifers contains only tracheids. In woody plants, the older xylem ceases to participate in water transport and simply serves to give strength to the trunk.
Phloem: The main components of phloem are to *sieve elements* and *companion cells*.
Sieve elements are so-named because their end walls are perforated. This allows cytoplasmic connections between vertically-stacked cells. The result is a sieve tube that conducts the products of photosynthesis - sugars and amino acids - from the place where they are manufactured (source) to the places (sinks) where they are consumed or stored; such as roots, growing tips of stems and leaves, flowers, fruits, tubers, corms, etc. Sieve elements have no nucleus and only a sparse collection of other organelles. They depend on the adjacent companion cells for many functions.
Companion cells move sugars and amino acids into and out of the sieve elements. In "source" tissue, such as a leaf, the companion cells use transmembrane proteins to take up (by active transport) sugars and amino acids from the cells manufacturing them. Water follows by osmosis. These materials then move into adjacent sieve elements by diffusion through plasmodesmata. The pressure created by osmosis drives the flow of materials through the sieve tubes. In "sink" tissue, the sugars and amino acids leave the sieve tubes by diffusion through plasmodesmata connecting the sieve elements to the cells of their destination. Again, water follows by osmosis where it may leave the plant by transpiration or increase the volume of the cells or move into the xylem for recycling through the plant.

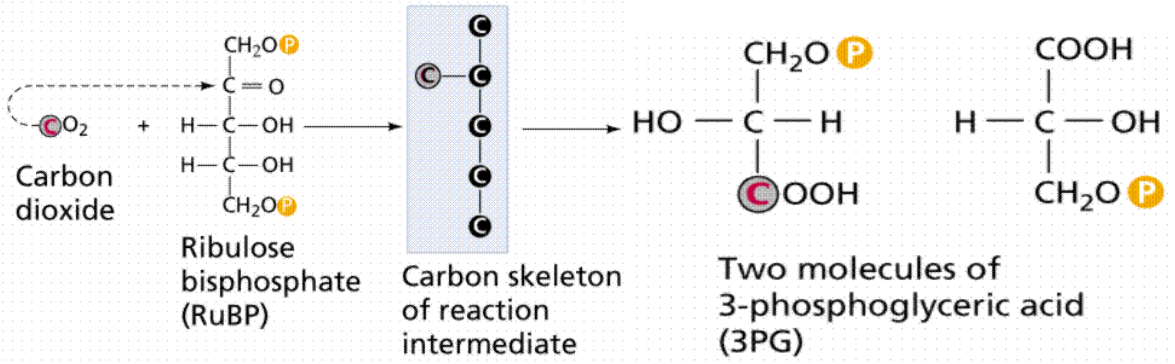


The energy harvested via the light reaction is stored by forming a chemical called ATP (adenosine triphosphate), a compound used by cells for energy storage. This chemical is made of the nucleotide adenine bonded to a ribose sugar, and that is bonded to three phosphate groups. This molecule is very similar to the building blocks for our DNA.



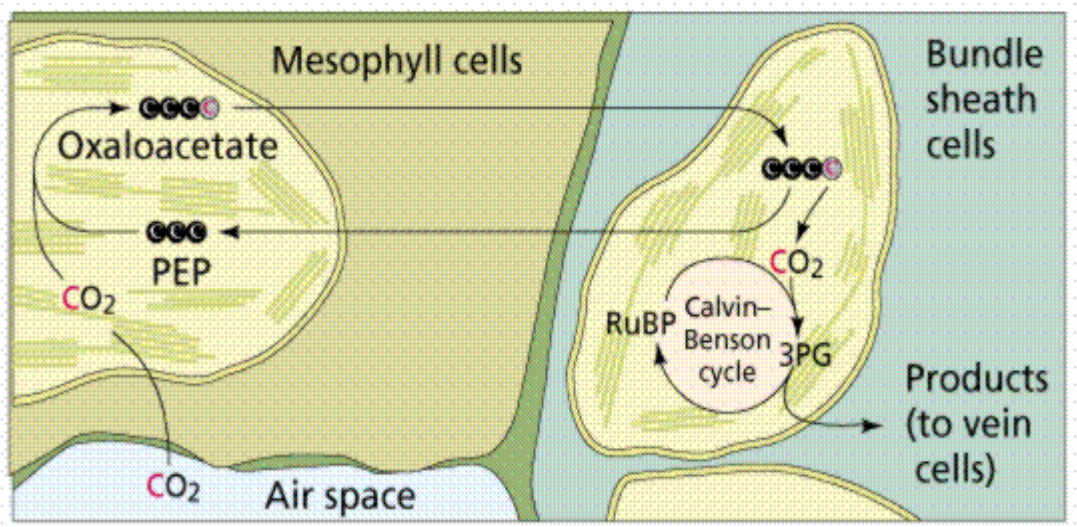
In the Light Dependent Processes (Light Reactions) light strikes chlorophyll a, this excites electrons to a higher energy state. In a series of reactions the energy is converted (along an electron transport process) into ATP and NADPH. Water is split in the process, releasing oxygen as a by-product of the reaction. The ATP and NADPH are used to make C-C bonds in the Light Independent Process (Dark Reactions).

In the Light Independent Process, carbon dioxide from the atmosphere (or water for aquatic/marine organisms) is captured and modified by the addition of Hydrogen to form carbohydrates (general formula of carbohydrates is CH_2O_n). The incorporation of carbon dioxide into organic compounds is known as carbon fixation. The energy for this comes from the first phase of the photosynthetic process. Living systems cannot directly utilize light energy, but can, through a complicated series of reactions, convert it into C-C bond energy that can be released by glycolysis and other metabolic processes. The dark reaction takes place in the stroma within the chloroplast, and converts CO_2 to sugar. This reaction doesn't directly require light in order to occur, but it does require the products of the light reaction (ATP and another chemical called NADPH). The dark reaction involves a cycle called the Calvin cycle in which CO_2 and energy from ATP are used to form sugar. Carbon dioxide is captured by the chemical ribulose biphosphate (RuBP). RuBP is a 5-C chemical. The first product of photosynthesis is a three-carbon compound called glyceraldehyde 3-phosphate. Almost immediately, two of these join to form a glucose molecule. Most plants put CO_2 directly into the Calvin cycle. Thus the first stable organic compound formed is the glyceraldehyde 3-phosphate. Since that molecule contains three carbon atoms, these plants are called C_3 plants. For all plants, hot summer weather increases the amount of water that evaporates from the plant. Plants decrease the amount of water that evaporates by keeping their stomates closed during hot, dry weather. Unfortunately, this means that once the CO_2 in their leaves reaches a low level, they must stop doing photosynthesis. Even if there is a small portion of CO_2 left, the enzymes used to transfer it into the Calvin cycle don't have enough CO_2 to use. Grass in our gardens just turns brown and goes dormant. Some plants like crabgrass, corn, and sugar cane have a special modification to conserve water. These plants capture CO_2 in a different way: they do an extra step first, before doing the Calvin cycle. These plants have a special enzyme that can work better, even at very low CO_2 levels, to capture CO_2 and turn it first into oxaloacetate, which contains four carbons. Thus, these plants are called C_4 plants. The CO_2 is then released from the oxaloacetate and put into the Calvin cycle. This is why crabgrass can stay green and keep growing when all the rest of your grass is dried up and brown. There is another strategy to cope with very hot, dry, desert weather and conserve water. Some plants (for example, cacti and pineapple) that live in extremely hot, dry areas like deserts, can only safely open their stomata's at night when the weather is cool. Thus, there is no chance for them to get the CO_2 needed for the dark reaction during the daytime. At night when they can open their stomata's and take in CO_2, these plants incorporate the CO_2 into various organic compounds to store it. In the daytime, when the light reaction is occurring and ATP is available (but the stomata's must remain closed), they take the CO_2 from these organic compounds and put it into the Calvin cycle. These plants are called CAM plants, which stands for crassulacean acid metabolism after the plant family, Crassulaceae (which includes the garden plant *Sedum*) where this process was first discovered.



The first stable product of the Calvin Cycle is phosphoglycerate (PGA), a 3-C chemical. The energy from ATP and NADPH energy carriers generated by the photosystems is used to attach phosphates to (phosphorylate) the PGA. Eventually there are 12 molecules of glyceraldehyde phosphate (also known as phosphoglyceraldehyde or PGAL, a 3-C), two of which are removed from the cycle to make a glucose. The remaining PGAL molecules are converted by ATP energy to reform 6 RuBP molecules, and thus start the cycle again. Remember the complexity of life, each reaction in this process, as in Kreb's Cycle, is catalyzed by a different reaction-specific enzyme. .

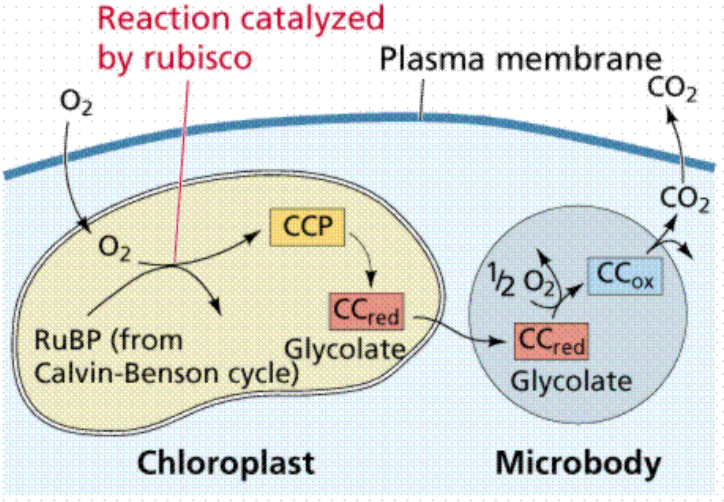
C-4 Pathway - Some plants have developed a preliminary step to the Calvin Cycle (which is also referred to as a C-3 pathway), this preamble step is known as C-4. While most C-fixation begins with RuBP, C-4 begins with a new molecule, phosphoenolpyruvate (PEP), a 3-C chemical that is converted into oxaloacetic acid (OAA, a 4-C chemical) when carbon dioxide is combined with PEP. The OAA is converted to Malic Acid and then transported from the mesophyll cell into the bundle-sheath cell, where OAA is broken down into PEP plus carbon dioxide. The carbon dioxide then enters the Calvin Cycle, with PEP returning to the mesophyll cell. The resulting sugars are now adjacent to the leaf veins and can readily be transported throughout the plant.



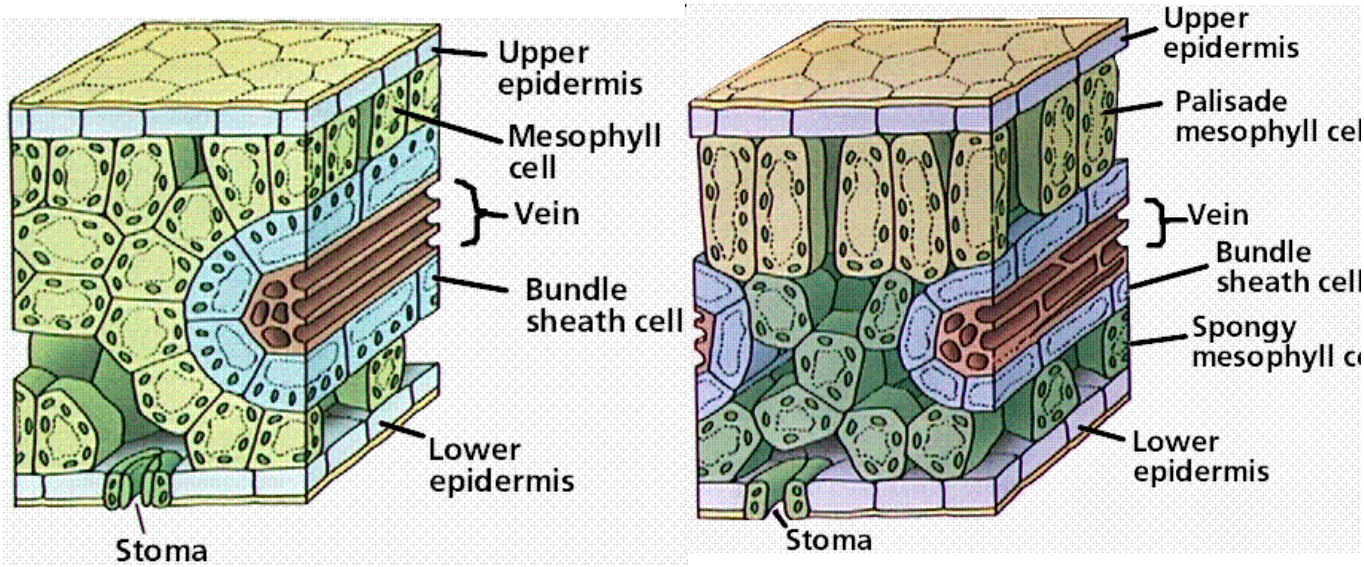
C-4 photosynthesis involves the separation of carbon fixation and carbohydrate.

The capture of carbon dioxide by PEP is mediated by the enzyme PEP carboxylase, which has a stronger affinity for carbon dioxide than does RuBP carboxylase. When carbon

dioxide levels decline below the threshold for RuBP carboxylase, RuBP is catalyzed with oxygen instead of carbon dioxide. The product of that reaction forms glycolic acid, a chemical that can be broken down by photorespiration, producing neither NADH nor ATP, in effect dismantling the Calvin Cycle. C-4 plants, which often grow close together, have had to adjust to decreased levels of carbon dioxide by artificially raising the carbon dioxide concentration in certain cells to prevent photorespiration. C-4 plants evolved in the tropics and are adapted to higher temperatures than are the C-3 plants found at higher latitudes. Common C-4 plants include crabgrass, corn, and sugar cane. Note that OAA and Malic Acid also have functions in other processes, thus the chemicals would have been present in all plants, leading scientists to hypothesize that C-4 mechanisms evolved several times independently in response to a similar environmental condition, a type of evolution known as convergent evolution.



We can see anatomical differences between C3 and C4 leaves.



Leaf anatomy of a C3 (right) and C4 (left) plant. Images from Purves et al., Life: The Science of Biology, 4th Edition

Starch in leaves- when plants photosynthesize they make glucose. Glucose molecules are quite small for organic molecules and dissolve easily in water. They also react quite easily with other molecules. So they are not very good for keeping in a cell for a long time. If a plant needs to store glucose molecules, it turns them into starch molecules. A starch molecule is very big and is made of hundreds or thousands of glucose molecules linked together. Natural starch molecules do not dissolve in water. Although they are very long, they curl up tightly, so they fit into a small space. A leaf which has been photosynthesizing will have a lot of starch molecules in it. The starch is in the form of starch grains inside the chloroplasts in the mesophyll cells.
To find out if leaf has been photosynthesizing it has to be tested for starch. Starch turns blue-black when iodine solution has been added to it. The cell membrane in the leaf has to be broken down first, so that the iodine solution can get to the chloroplasts and reach the starch. Also the green color in the leaf has to be removed, if not it is very difficult to tell what color the iodine solution turns.

Variables

Input variable-light intensity- is varied by increasing or decreasing the distance from the light source (lamp) to the plant (elodea).

Output variable-volume of oxygen produced (rate of photosynthesis)-is going to be measured by finding the volume of oxygen evolved in one minute.

Controllable variables-light wavelength (colour) - As I have mentioned previously light energy is absorbed by the pigment 'chlorophyll'. Chlorophyll blue and red light, however doesn't absorb green and yellow light. It reflects them decreasing the amount of overall light absorbed therefore also decreasing the rate of photosynthesis. This problem can be easily controlled by using the same lamp throughout the experiment.

CO_2 Concentration- This can affect the rate of photosynthesis. If there is a very little amount of CO_2, it can become the limiting factor and thus becoming a physical defect in the experiment. However as long as the experiment is done over a short period of time, the amount of CO_2 used up by the plant will not be sufficient enough to cause the CO_2 concentration to turn into the limiting factor. If the experiment were to be carried out over a longer period of time for example 24 hours, then a fixed amount of sodium bicarbonate will have to be added to the water which will ensure a large enough supply of CO_2.

Water Availability- Water is required during photosynthesis. In drought conditions the stomata in the leaf closes to prevent further water loss. This leads too little CO_2 being able to diffuse through. Obviously when using water plants such as elodea this isn't a problem as long as it is fully submerged under the water at all times.

Temperature- Enzymes are used in the photosynthesis reactions of a plant. Therefore, temperature will increase the rate of photosynthesis, until a certain point at which the enzymes denature. Although performing the experiment at a temperature slightly higher than room temperature, perhaps 25 degrees would have a positive effect on the accuracy of

the readings taken, as it would reduce the temperature error, by increasing the volumes however the inaccuracy of maintaining a constant temperature would outweigh any advantages. Therefore the experiment should be performed at room temperature, checking the temperature frequently, in case heat given off from the light should slightly raise the temperature, in which case the beaker will have to be refilled with more water after each experiment.

Prediction

I predicted that as the intensity of light is increased (moving the light closer to the *elodea*) the rate of photosynthesis will also increase. This is because the light that falls on the chloroplasts in the leaf is trapped by the chlorophyll. This creates energy for the chemical reactions in the plant. Therefore as the intensity of light is increased, more energy is absorbed for the chemical reactions to take place, thus the rate of photosynthesis rises. However the rate of photosynthesis will increase at a proportional rate until a certain level is reached. As the level is reached further increase in light intensity will have no effect as there will be another limiting factor which will be in effect, either temperature or carbon dioxide concentration.

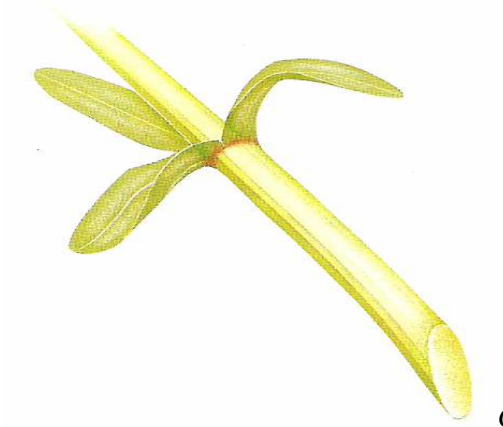
Preliminary Experiment (Trial run 1)

Equipment List	Purpose
Scalpet	To cut the elodea
Ruler	To measure distance between light and elodea
Beaker	To hold H_2O
Stopwatch	To measure the time
Light (lamp)	The source of 'synthesized sun'
Sodium Bicarbonate	To provide CO_2
Pondweed (elodea)	To photosynthesize
Measuring Cylinder	To measure the volume of O_2 evolved
Filter Funnel	To channel bubbles to measuring cylinder

Method

1. Collect equipment and set up as shown in diagram below-

2. Cut the stem of the elodea at a 45 degree angle (as shown below). This allows water to be transported up the xylem.



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3. Allow the elodea to acclimatize in the new water.

4. Record the temperature at the beginning and at the end of each experiment. This acts as a precaution in case there is a rise in temperature. The temperature may rise becoming the limiting factor as there is heat being released for the lamp. However this is not expected.

5. Set up the lamp at 100cm and start the stopwatch, record the volume of O_2 evolved after 1minute.

6. Repeat procedure at the following distances: 80cm, 60cm, 40cm, 20cm (or whatever distances you decide upon)

7. Repeat a further 2 times at all distances decided upon. This gives you an average result to work from for each of the distances. It also allows the elodea to acclimatize to the water.

8. If the water temperature rises simply empty and refill the beaker with more water.

Safety is the most important when carrying out experiments in a science lab. The rules are displayed below-
1. Stand up when carrying out experiments as liquid substances may spill onto clothing.
2. Cut elodea on a provided tile and away from the body.
3. Keep lamp away from contact with water.
4. The bulb in the lamp may be hot after a long period of time so it is advised not to touch or attempt in removing it.

Fair Test
To ensure that a fair test is carried out the following things must be done
- The same pondweed must be used every time the light distance is changed.
- The experiment must be repeated at least 2 times to get an accurate result and an average.
- The same amount of sodium bicarbonate will have to be kept throughout the experiment.
- The temperature of the water will have to remain the same throughout the experiment.
- The experiment will be timed a 1 minute for each of the distances.

This experiment wasn't entirely accurate to be the basis of my experiment. The lack of inaccuracy was mainly due to the time factor. Although it produced a result the period in which the production of oxygen was timed was very limited. If the experiment was stretched from 1 minute to for example 24 hours, this will give us a higher reading and an accurate result to plot on the graph. Therefore I will have to carry out another experiment to obtain an accurate result. I will be using a different method -

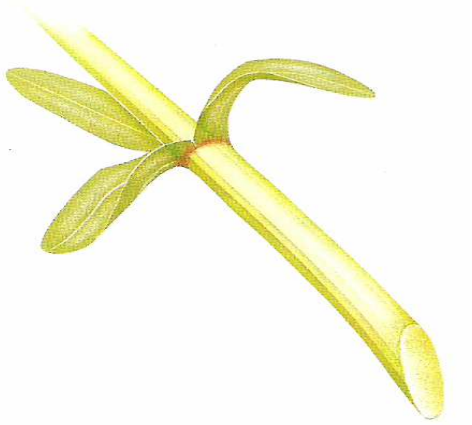
Main Experiment

Scalpet	To cut the elodea
Ruler	To measure distance between light and elodea
Stopwatch	To measure the time
Light (lamp)	The source of 'synthesized sun'
Sodium Bicarbonate	To provide CO_2
Pondweed (elodea)	To photosynthesize
Measuring Cylinder	Hold H_2O

Method

1. Collect equipment and set up as shown in diagram below-

2. Cut the stem of the elodea at a 45 degree angle (as shown below). This allows water to be transported up the xylem.



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3. Allow the elodea to acclimatize in the new water.

4. Record the temperature at the beginning and at the end of each experiment. This acts as a precaution in case there is a rise in temperature. The temperature may rise becoming the limiting factor as there is heat being released for the lamp. However this is not expected.

5. Set up lamp at 10cm and start stop watch after first bubble is formed. Record number of bubbles formed after one minute.

6. Repeat procedure at the following distances: 80cm, 60cm, 40cm, 20cm (or whatever distances you decide upon)

7. Repeat a further 2 times at all distances decided upon. This gives you an average result to work from for each of the distances. It also allows the elodea to acclimatize to the water.

8. If the water temperature rises simply empty and refill the beaker with more water.

Results Table

Distance from light (cm)	Time (minutes)	Try 1	Try 2	Try 3	Average	Temperature (degrees)
20	1	5	15	25	15	21
40	1	3	5	7	5	23
60	1	0	1	3	1.33	19
80	1	0	0	3	1	21
100	1	0	0	0	0	20

Observations/ Analysis

I drew my graph from the results I collected in the form of a best fit curve. My main experiment produced a clear pattern of points which enabled me to draw a curve rather than a straight line. This shows that the rate of photosynthesis increased as light intensity increased (the lamp was moved closer to the elodea). I can prove this by taking the following section from my results table;

60cm	1.33 bubbles
40cm	5 bubbles
20cm	15 bubbles

This is because photosynthesis is a reaction needing to absorb energy from light for chemical reactions in the plant. So as the amount of energy is available from the light increases with the rise in light intensity, so does the amount of oxygen produced as a product of photosynthesis.

After reviewing my results table I have realized that it would not be necessary to take results further than 60cm as there is not much of a difference between results after this point. However it would be better to record further readings between the distances of 20cm and 40cm as the readings between these points are large in comparison to the results between different distances. Therefore if I had another chance in attempting this experiment I wound have to take readings from the following distances – 20cm, 25cm, 30cm, 35cm, 40cm, 50cm and 60cm.

Unexpectedly my hypothesis wasn't entirely correct. The increase in the rate of photosynthesis was not directly proportional to the increase in light intensity. This could be due to the fact that the temperature of the water was not monitored and was different in each of the readings. If the temperature climbed then the rate of photosynthesis would speed up, whereas if the temperature dropped then the rate of photosynthesis would slow down. However although the results was not directly proportional, the idea that as light intensity increased the rate of photosynthesis would also increase, was comprehensively backed up by the best fit curve on the graph. This is because a higher light intensity involves a greater level of light energy, which can then be transferred to a special protein environment designed to convert the energy. The energy of a photon is used to transfer electrons from one chlorophyll pigment to the next. When enough energy has been gathered at a reaction centre, ATP can be synthesized from ADP. The oxygen collected in the experiment is in fact the by-product of this reaction, and so it is clear to see that the more light energy, the more ADP is being converted into ATP and more oxygen is produced as a result.

Evaluation

Although I feel this investigation went quite well, I thought there were a few points at which the accuracy was not perfect. As I have previously mentioned my preliminary experiment wasn't entirely accurate to be the basis of my experiment. Mostly due to the time factor. Although it produced a result the period in which the production of oxygen was timed was very limited which gave a very low reading however any of the smaller inaccuracies also apply to my main experiment.

The first error in this investigation would have been due to the background light in the surrounding area. This factor was not taken into consideration at all before or during the tests taking place so the laboratory blinds were not closed therefore sunlight may have affected the elodea. This would have had a very marginal effect on my results as a whole, but eliminate this problem completely, it would have been necessary to perform the experiment in a totally dark room.

A further inaccuracy was in the heat generated by the lamp. As I have previously described, a temperature change could seriously alter and produce inaccurate results. Furthermore as shown in the results table the temperature varied from 19˚c to 23˚c. The amount of oxygen produced in each try could have been inaccurate. One way that I could reduce the production errors and keep the temperature constant would be to place a Perspex block between the lamp and the elodea which would absorb most of the heat, while allowing the light energy to pass through it.

Even though carbon dioxide concentration could have been an error in the experiment it is unlikely that over a short period of time the concentration would have been so low as to become the limiting factor. However if I were to perform this experiment over a longer period time the amount of CO_2 will have to be measured and add sodium hydrogen carbonate to the water to increase CO_2 concentration where necessary.

Finally the last inaccuracy was time keeping. If we began timing just after the first bubble had been produced and in another reading it was just before, it could have had a negative effect on the accuracy of my results. Therefore on each I started just after the first bubble had been produced which increased the accuracy.

Overall, I think that due to the fact that we were experimenting with small volumes of oxygen, it wasn't that accurate however enough to support and justify my hypothesis. Improvements could have been made as I have stated, but due to consequential problems related to these adjustments it was not possible.

To extend this investigation into the rate of photosynthesis, I could try to involve some of the other limiting factors to the same experiment. It could also be interesting to explore the effects of colored lights on the rate of photosynthesis.