Experiment to investigate the effect of Carbon Dioxide on the Rate of Photosynthesis

Aim:
To find out whether the increase in carbon dioxide affects the rate at which oxygen is released (this will effectively measure the rate of photosynthesis) from a Canadian pondweed, elodea.

Introduction:
Photosynthesis is the trapping of light energy to make glucose in plants. It is very important to all living organisms as it produces oxygen as an excretory product, which humans depend on.

$$6H_2O + 6CO2 \xrightarrow[\text{chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O2$$

Water + carbon dioxide → glucose + oxygen

It can be seen from the equation that water and carbon dioxide are very important in photosynthesis as without the process cannot take place. Once the leaf has these, it uses the chlorophyll to trap sunlight it then releases oxygen as a waste product. Finally the product (glucose), is transported to other parts of the plant or it is stored somewhere. Carbon dioxide provides carbon atoms in the reaction to form glucose.
It can be seen that there are many factors which photosynthesis depends on and they will affect the plant. The following factors are the four main factors, which affect the rate of photosynthesis (how quickly photosynthesis takes place).

Carbon dioxide
Water
Sunlight
Temperature

As the variable being investigated is carbon dioxide, it will be shown how carbon dioxide affects the rate of photosynthesis:

Before deducing a hypothesis an in depth knowledge of the process of photosynthesis is required. One of the main factors is to consider how carbon dioxide enters the palisade cell. Carbon dioxide enters the leaf via stomata on the lower epidermis of the leaf. The process by which carbon dioxide enters the cell is diffusion. The stomata can be considered as pores. The leaf has a method by which to control the opening and closing of these pores.

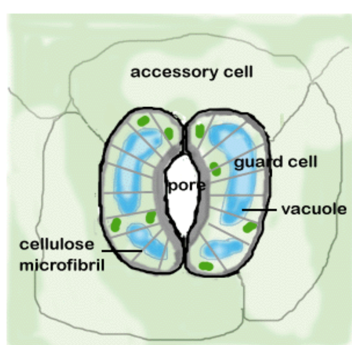
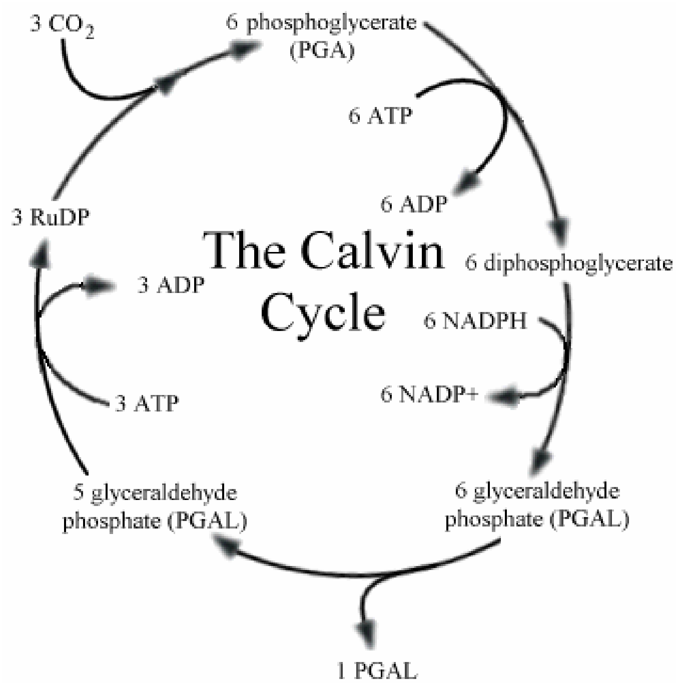


Figure 1 shows the structure of the stomata. Adjacent to the pore (stoma), are two guard cells. Changes in turgidity of these guard cells causes them to change shape so they are either open or closed. Thus the number of stomata present will affect the amount of carbon dioxide available to the leaf.

Another important consideration is the utilisation of carbon dioxide. Carbon dioxide enters into the stroma of the chloroplast and becomes part of a cycle of events known as the Calvin cycle, the outcome of which is glucose a 6-Carbon sugar. Carbon dioxide enters the cycle and fixes to a 5-carbon sugar known as ribulose bisphosphate (RuBP). An enzyme known as Ribulose bisphosphate carboxylase casually called Rubisco catalyses the reaction. This is thought to be the most abundant enzyme on Earth. Enzymes are susceptible to a process known as saturation. This is because enzymes work by bringing two substrates (in this case RuBP and co2) together. In simple terms this relates to the fact that at any given time one enzyme can only accommodate one reaction between the two substrates, so once all the enzymes present are active the rate of reaction will not increase regardless of whether the concentration of the substrates (CO_2) is increased.



Sodium Hydrogen Carbonate ($NaHCO_3$) is known to release carbon dioxide as a gas when mixed with water or acid. The equation below shows this:

$$NaHCO_{3\,(aq)} + H_2O_{(aq)} \rightarrow NaOH_{(aq)} + CO_2 + H_2O$$

The equation shows how carbon dioxide is released when sodium hydrogen carbonate is mixed with hydrochloric acid, $NaHCO_3$ reacts in the same way when dissolved in water – it releases carbon dioxide as a gas.

<u>Hypothesis:</u>

The more carbon dioxide there is, the more oxygen will be produced therefore increasing the rate of photosynthesis. This will take place until saturation, which is when the reaction will be taking place at its maximum.

It is known from theoretical study that if the carbon dioxide is doubled, the rate of photosynthesis also doubles, so this shows that the rate of photosynthesis will increase with the increase of carbon dioxide. This is due to the fact that the plant will have more carbon dioxide so the reaction can take place faster. When the rate of photosynthesis stops increasing as much this will be because of saturation and the fact that the reaction is running at its maximum or because there are other limiting factors limiting the rate of the reaction.

To measure the amount of carbon dioxide, the substrate sodium hydrogen carbonate is being used as it releases carbon dioxide as a gas, and the more of it that is dissolved into the water; the more carbon dioxide is released, therefore increasing the rate of photosynthesis.

<u>Fair Test:</u>

To make sure that the results are reliable, a fair test must be carried out and planned. The following things must be kept the same:

1. The amount of water in the beaker and the test tube, which has the elodea, will be kept the same every time as water is a factor, which affects the rate of photosynthesis because if there is a slight amount of water deficiency then it can lead to the plant wilting temporarily. The reason for this is that the plants close their stomata when wilting occurs so the CO_2 cannot get through and so this would obviously affect the rate of photosynthesis.
2. The distance the lamp is from the plant (light intensity) will be kept the same, as light is also a factor, which affects the rate of photosynthesis. Light affects the rate because if there is more light it is like giving the plant more food and therefore it will have more energy.
3. The temperature of the water must be kept the same as temperature affects the way the enzymes work and the temperature will affect how quickly the reaction takes place. This can be kept the same by monitoring the temperature every time a result is taken down. This will help in analysing the results as the temperature can be taken into account.
4. The same elodea will be used each time as different elodeas may produce the bubbles at different rates. If different elodeas are used then the test is not fair because the elodeas may be different sizes and have different conditions, also keeping the same elodea helps to monitor the amount of chlorophyll. Chlorophyll also affects the rate of photosynthesis. The elodea must react in the same way for each experiment so if different elodeas are used then they may react in a different way.

Apparatus:

To carry out this investigation, the following equipment will be needed:

- 3 beakers to keep the elodeas and the test tubes in.
- 3 test tubes to keep the elodea and the pond water in.
- Stopwatch to time how long the amount of bubbles being released needs to be counted for.
- Thermometer to take the temperature and later on see if the temperature would have made any effect on the rate, if it were different.
- Weighing scales to measure how much sodium hydrogen carbonate is needed.
- Spatula to take the sodium hydrogen carbonate from the bottle.
- Lamp to give the plant some light.
- Sodium hydrogen carbonate ($NaHCO_3$). This has been chosen because it is easily available and is a simple way of measuring carbon dioxide.
- Elodea, this is being used as the pondweed has a unique characteristic of releasing oxygen bubbles when under water.

Method:

1. Fill a beaker with water and place a test tube with a piece of elodea and water from the pond the elodea came from, into the beaker.
2. Place a lamp next to the beaker and using a thermometer, measure the temperature of the water in the beaker.
3. Place 0.2grams of sodium hydrogen carbonate into the beaker and leave the beaker for two minutes so the plant can adjust to the new amount. Then start the stopwatch and count the number of bubbles released from the elodea using a tally counter. Only count the bubbles, which are moving as many bubbles may get counted more than once if the non-moving bubbles are also counted as the bubbles stop moving in the test tube after a while.
4. Then get another 0.2grams of sodium hydrogen carbonate and add it to the beaker. Take the temperature and begin counting the number of bubbles again for one minute.
5. Keep adding 0.2grams of $NaHCO_3$ until 1 gram is reached.
6. Throughout the experiment make sure the lamp is always the same distance from the beaker to prevent light becoming an influencing factor.

Preliminary Work:

Preliminary work that was done was to measure the amount of oxygen bubbles released from the elodea when the plant has different amounts of carbon dioxide in the water. This was done to try and test whether or not the amount of CO_2 would affect the rate of photosynthesis. Below the results of the preliminary experiment are shown:

No. Of oxygen bubbles released

CO_2-NahCO$_3$ concentration (grams)	1st result	2nd result	3rd result	Average	Temp. Of water °C
0	2	4	2	3	19
0.4	212	229	208	216	23
0.8	402	462	398	421	24
1.2	512	487	499	498	25

From the results it can be seen as the amount of sodium hydrogen carbonate added is increased, the number of oxygen bubbles released also increases. However, it can be seen that the difference between the first result and the next is decreasing; this shows that the reaction is reaching the substrates limit. The results prove that saturation is taking place in the plant. It also shows that when there was no carbon dioxide added, bubbles were still being produced, this was because the plant uses the carbon dioxide available in the atmosphere.

Modifications

The following modifications will be made to the way the experiment would be carried out after the preliminary experiment had been done:

1. The concentration amounts will be changed from being 0.4grams each time to 0.2grams. The reason for this change was because, 0.4g was producing many results and when another amount of 0.4g would be added it would be very difficult to count all the bubbles being produced. With 0.2g being the concentration, more results could be obtained and the results would be more accurate as not as many bubbles would be being produced rapidly.
2. Also, when counting the bubbles it was seen that a lot of human error was involved so to reduce this, a tally counter will be used to count the number of bubbles being released from the plant.
3. The amount of time the bubbles would be counted for was 2 minutes at first, but because there are so many bubbles being produced, the time will be reduced to 1 minute so the results are likely to be more accurate.

Reliability:

It is essential that the experiment carried out is reliable otherwise the conclusions reached cannot be said to be accurate or reliable. To make the experiment reliable certain steps have been taken. An accurate weighing scale is being used which has an accuracy of 0.01grams, which makes the results more accurate and precise. Also, to make the collected valid and reliable the experiment can be repeated more than once and then the average can then be found of all the results for that particular amount of sodium hydrogen carbonate. The experiment can be repeated three times, which is a decent amount of times to repeat the experiment.

Safety:

To make sure the experiment is done safely, the following precautions will be taken:

1. All glassware will be handled carefully.
2. It will be made sure that hands are washed after using the sodium hydrogen carbonate otherwise it could be dangerous.

The following results were collected from doing the experiment. In the table all three results collected have been shown and adding the three results and dividing the value by three have found the average of the three results.

The amount of sodium hydrogen carbonate was measured in grams and the temperature was taken in degrees (Celsius).

	No. Of bubbles released				
CO_2-$NaHCO_3$ concentration (grams)	1st Result	2nd Result	3rd Result	Average number of bubbles	Temperature °C
0	0	0	0	0	23
0.2	109	98	86	98	23
0.4	139	149	114	134	23
0.6	168	188	175	177	23
0.8	198	225	235	219	24
1	232	238	242	237	23

$NaHCO_3$ Concentration (grams)	Average number of bubbles released	Number of bubbles per second[1] (rate of photosynthesis)
0	0	0
0.2	98	1.63
0.4	134	2.23
0.6	177	2.95
0.8	219	3.65
1	237	3.95

The above table shows the rate of photosynthesis, which was worked out by using the following formula:

Number of bubbles produced/Time (60 seconds) = Rate

On the following pages are two line graph, the first shows the concentration and the number of bubbles produced and the other shows the concentration and the rate of photosynthesis. On the second graph the gradient calculations have been drawn on.

Analysis:

From the results that have been obtained it is clear to see that they indicate that as the concentration of carbon dioxide is increased so does the rate of photosynthesis, in simple terms as the amount in grams of sodium hydrogen carbonate is increased the number of bubbles released from the elodea also increases, this is known as a directly proportional relationship. It is essential that a clear trend or pattern is recognised from the results and again as mentioned above the pattern of the results is that as the amount of carbon dioxide available to a plant is increased the rate of photosynthesis also increases. The conclusion given can be re-enforced by the table of results that has been given, if the average number of bubbles for 0.2 grams is looked at then it can be seen that 98 bubbles are released but if the same recording is analysed for 0.6 grams then an average of 177 bubbles are produced. This infers a clear pattern that has mentioned above.

The pattern is clearly illustrated by graph 1, which shows a linear progression i.e. again a directly proportional relationship. The initial prediction that was made and the aim of the investigation were to find out the affect of carbon dioxide on the rate of photosynthesis. The rate of photosynthesis can be assessed as being the number of bubbles released in one second. Thus for each concentration the number of bubbles per second can be calculated. This has been done in table two. If this table is interpreted it can be seen that the rate of photosynthesis increases as the concentration increases. From this information a graph can be drawn of rate of photosynthesis against concentration or carbon dioxide.

Significantly, the results match the prediction that was given. This indicates that the theory that the prediction was based on was correct. Thus one can draw conclusions from the findings and relate these to scientific knowledge.

It is known that photosynthesis requires carbon dioxide to proceed. Photosynthesis is utilised in the reaction to make glucose. The role of carbon dioxide is to diffuse into the leaf and take part in the Calvin cycle where it is fixed onto a 5-carbon sugar. As the concentration of Carbon dioxide increases the amount of carbon dioxide available to take part in the reaction with the 5-carbon sugar, also increases. Thus, so does the rate of reaction i.e. the number of bubbles released from the elodea.

Photosynthesis is a complex process that is affected by many factors. In the prediction it was assumed that as the concentration of carbon dioxide is doubled so will the rates of photosynthesis, however, this does not seem to be the case although there is a directly proportional relationship. An observation of the results illustrates that as the concentration is increased from 0.8 to 1 gram the increase in the rate of photosynthesis decreases. The reason for this may be related to the fact that carbon dioxide is no longer a limiting factor in photosynthesis. A limiting factor in a multi-factor affected reaction is the factor that is in short supply. For example, when the concentration of carbon dioxide is low, but the temperature, light intensity and water are available carbon dioxide is the limiting factor. Thus a slight increase in carbon dioxide result in a sharp increase in the rate of reaction. But when the concentration of carbon dioxide is high another factor will become limiting i.e. the factor in short supply. At the high concentrations of carbon dioxide another factor becomes limiting, thus an increase in carbon dioxide no longer results in such a sharp increase. It can be concluded that the results obtained back up the original prediction that was made, but it is also clear as photosynthesis is affected by many factors simply doubling the carbon dioxide would not double the rate of reaction. Thus this indicates that the quantitative prediction given was incorrect.

Evaluation:

The techniques that have been used can be said to have been suitable for the desired task, the reason for this is that the results that have been obtained show a clear trend and also directly correlate with the prediction that was made. Also a procedure was obtained that allowed the accurate measurement of the rate of photosynthesis with the concentration of carbon dioxide as the variable. The results that were obtained were reliable and consistent. Also they had a high level of repeatability, as the difference between repeated readings was small again enhancing the reliability of the results. This is a clear indication that a suitable method and technique was used.

The reliability of the experiment was high due to the fact that the repeated readings for each concentration are very close for example at 0.2M the difference in the change in mass is only 0.01g. The experiment was also reliable because variables were controlled such as the temperature were kept the same. Also the apparatus was accurate and to high precision meaning that the results were reliable. The evidence for this is that the difference between repeated readings is small and also apart from the one anomalous result all the others lie close to the line of best fit indicating that the results were reliable.