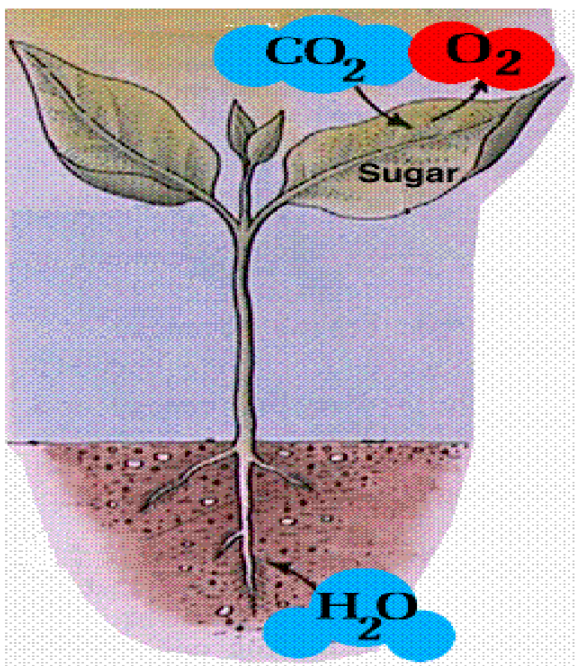
AT$_2$ Biology

Investigating Factors Affecting the Rate of Photosynthesis



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How does Light Intensity Affect the Rate of Photosynthesis?

Aim

The aim of this coursework is to investigate whether light intensity affects the rate of photosynthesis. To do this, I will place a piece of Canadian pondweed in varying light intensities and observe the amount of oxygen given off.

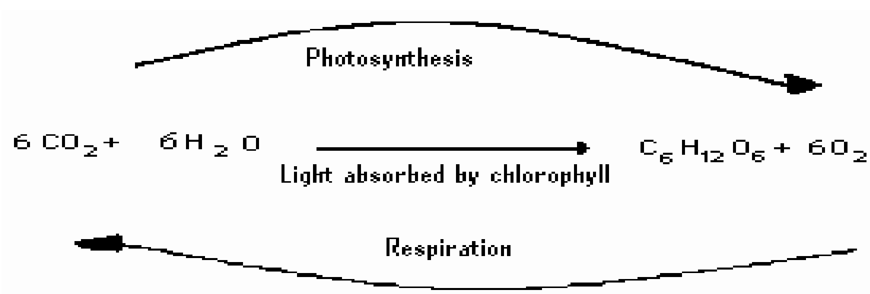
Introduction
Photosynthesis is the process by which green plants and certain other organisms transform light into chemical energy. In green plants, light energy is captured by chlorophyll in the chloroplasts found in the palisade cells of the leaves and used to concert water, carbon dioxide and minerals into oxygen and energy rich organic compounds (sugar) that are the basis of both plants and animal life.

The first step in photosynthesis is Light Dependent Processes (Light Reaction). Light strikes chlorophyll in such a way as to excite electrons to a higher energy state. In a series of reaction, the energy is converted along an electron transport process into ATP (adenosine triphosphate) and NADPH (nicotinamide adenine dinucleotide phosphate). 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 next stage of photosynthesis, Light Independent Process (Dark Reaction).

In the Light Independent Process, carbon dioxide from the atmosphere is captured and modified by the addition of Hydrogen to form carbohydrates. The incorporation of carbon dioxide into organic compounds is known as carbon fixation.

Photosynthesis can be summarised as:

Carbon dioxide + water ⟶ Glucose + Oxygen



Prediction
I predict that as the distance of the light from the plant decreases (more light intensity), the rate of photosynthesis will increase up to a certain point. This is because the plant will reach a level where an increase in light intensity will have no further effect on the rate of photosynthesis, as there will be another limiting factor, in this case probably carbon dioxide or temperature.

Hypothesis
When chlorophyll absorbs light energy, the light energy cannot be immediately used for energy conversion. Instead the light energy is transferred to a special protein environment where energy conversion occurs. This happens by using the energy of a photon to transfer electrons from a chlorophyll pigment to the next. When enough light energy has been harnessed at a reaction centre, ATP can be synthesized from

ADP. During this reaction, oxygen is produced as a by-product and it is the oxygen bubbles that are being measured in this experiment. The greater the light intensity, the more light energy that can be transferred and harnessed as fuel reaction in photosynthesis.

Light intensity is inversely proportional to the distance squared because the light energy spreads out as it travels further and further from its source. Light energy travels along the circumference of an expanding circle. When light energy is released from a point, the energy is dispersed equally along the circumference. But since the circle is expanding, the circumference increases and the same light energy is distributed along a greater surface.

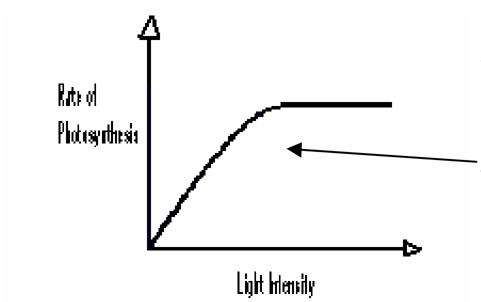
Factors
These four points illustrate important factors which affects the rate of photosynthesis:

- Light intensity
- Temperature
- Carbon dioxide Concentration
- Water availability

Other factors which will affect the rate of photosynthesis are:

- Surface area of leaf
- Light wavelength (Colour)
- pH (acidity) or (alkalinity)

Light intensity
As light increases, photosynthesis increases until the light compensation point (LCP) occurs. The LCP is the light level where photosynthesis and respiration balance each other; where CO_2 and O_2 will neither move into nor out of the leaf. Plant can survive at the LCP only as long as stored reserves are available.

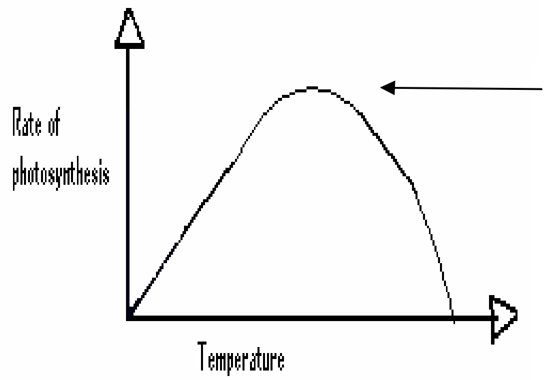


With increasing light levels, photosynthesis increases to a peak and then plateaus. This peak is called the light saturation point (LSP), after which there is no increase in photosynthesis with increasing light levels due to the plant being limited by a lack of increase in temperature or carbon dioxide.

The light intensity in the experiment is to be varied by increasing and decreasing the distance from the light source to the plant as my investigation is to investigate if light intensity affects the rate of photosynthesis.

Temperature

Enzymes are used in the respiration and photosynthesis reaction of a plant. Therefore increasing temperature will increase the rate of photosynthesis until a point at which the enzymes denature.

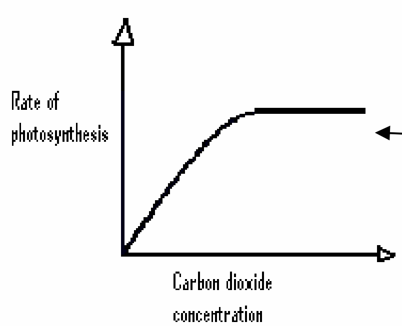


Above 40◦C, photosynthesis slows right down due to enzymes being denatured.

The experiment is going to be performed at room temperature therefore the temperature shouldn't change enough to affect the water temperature. The temperature can be controlled by using a large body of water and I will not let the experiment run for too as heat from the lamp may increase the temperature.

Carbon dioxide Concentration

Carbon dioxide concentration will affect the rate of reaction since the more carbon dioxide in the air, the more carbon dioxide that can diffuse into the leaf.



With more concentration of carbon dioxide, photosynthesis will increase at first but it is then limited by a lack of increase in temperature or light.

Sodium hydrogen carbonate is going to be added to the water to ensure that the rate of photosynthesis is not limited by carbon dioxide.

Water availability

Water is a raw material for photosynthesis and essential to the maintenance of cell and leaf. Any moisture deficiencies to the plant result in dehydration of cells and leaves wilting. These effects slow the rate of photosynthesis. When plants lack water, their stomata close to prevent further water loss. At the same time closing the stomata cells doesn't allow carbon dioxide to diffuse into the leaf. Water is therefore also linked to the carbon dioxide factor.

The plant used in this investigation is a water plant therefore submerging the plant in water at all times should not be a problem.

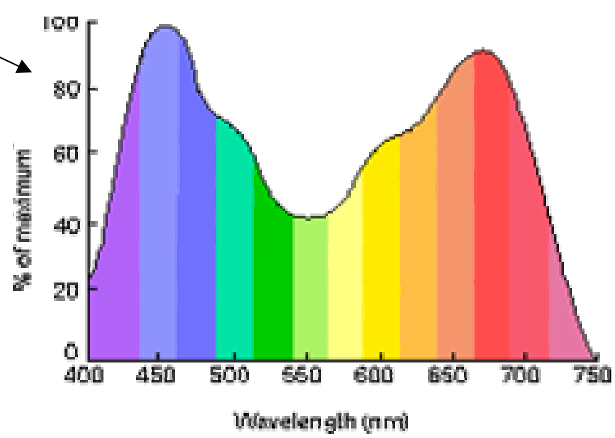
Surface area of leaf

The size of the plant leaf is important as this would affect the amount of surface area for gas exchange. Leaves are light, flat and thin because more light can be absorbed and carbon dioxide and oxygen can diffuse quickly and this increases the rate of photosynthesis.

In the investigation, the same plant will be used throughout the experiment to ensure that the surface area of the leaf is the same.

Light wavelength (Colour)

Light energy is absorbed by pigments in the leaf such as chlorophyll. Chlorophyll acts as a catalyst and absorbs mainly red, violet and blue light and reflect green light. The abundance of chlorophyll in leaves and its occasional presence in other plant tissues such as stems causes these plant parts to appear green.

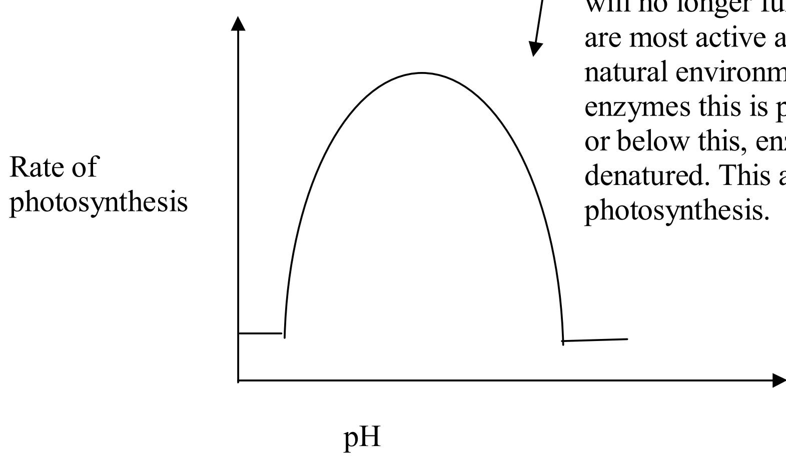


The light colour in the investigation can be fixed by using the same lamp throughout the experiment.

pH (acidity) or alkalinity)

pH is a measurement of the acidity or alkalinity of a substance. The scale of measurement is logarithmic ranging from 0 to 14. 7 is classed as neutral, 0 to 6.9 is acidic, and 7.1 to 14 is alkaline.

Enzymes are used in the process of photosynthesis. Enzymes are proteins which are sensitive to pH. pH affects the bonding of the protein. If the protein unfolds from its active configuration, it will no longer function. Enzymes are most active at the pH of their natural environment. For most enzymes this is pH 6 to 8. Above or below this, enzymes are denatured. This affects the photosynthesis.



Preliminary work

In my previous years, I carried out experiments to find out if light affects photosynthesis or not. To do this test, I used the following steps:

Apparatus

- Green leaf
- Foil
- A test tube
- Beaker
- Ethanol (alcohol)- to remove chlorophyll and break down cuticle
- Iodine- used to test for starch
- Water
- Bunsen burner
- A white board

Method

- Cover the middle of leaf with foil and leave in sunlight for a day
- Place Bunsen burner on white board and light the Bunsen burner
- Put water half full in the beaker and let it boil
- When water is boiled, turn Bunsen burner off
- Put ethanol in test tube (half full) and put leaf in it. Then put the test tube in hot water (Water boils at 100°C and the boiling point of ethanol is 60°C. This should boil the ethanol)
- When all the chlorophyll (green colour) is removed and the cuticle is broken down, take the leaf out and dry on white board.
- Put iodine on leaf
- Where there is starch produced by photosynthesis, it will turn blue/black but if there's no starch, it will just stay white.

In this experiment, I found out that light is needed in order for photosynthesis to take place. The middle part of the leaf was white while elsewhere turned blue/black. This was because there was no light supply in the middle of the leaf therefore photosynthesis did not take place as there was no starch produced. From the photosynthesis equation: (carbon dioxide + water (with light energy captured by chlorophyll) = glucose + oxygen), we know that there must be energy from light in order for photosynthesis to take place. Because the middle of the leaf did not have light energy supply, photosynthesis did not take place there.

As a result of finding out that light is needed in order for photosynthesis to take place, this is why I carried out another investigation to find out how the light intensity (how much light) will affect the rate of photosynthesis.

In this next experiment, I recorded the number of oxygen bubbles given off in a given time at various light intensities.

Preliminary results

Distance (Cm)	Number of bubbles per minute
5	47
10	40
15	36
20	32
25	30
30	24
35	20
40	17

Although this preliminary investigation gave me reasonable results, it is not efficient enough to use this as my main investigation. This is because sometimes I missed a few oxygen bubbles as a result of waiting for the bubbles to be roughly the same size. In my main investigation, I think I'm going to ignore the sizes of the bubbles and just count every bubble that is produced. I will also repeat the whole experiment twice and take the average result as this will make it more accurate.

Fair test

To ensure that a fair test is carried out, I am going to use the same pondweed every time I change the light distance. The experiment is going to be carried out twice for each distance to get an accurate average. Also I will only vary one variable which is the distance of the light source from the plant.

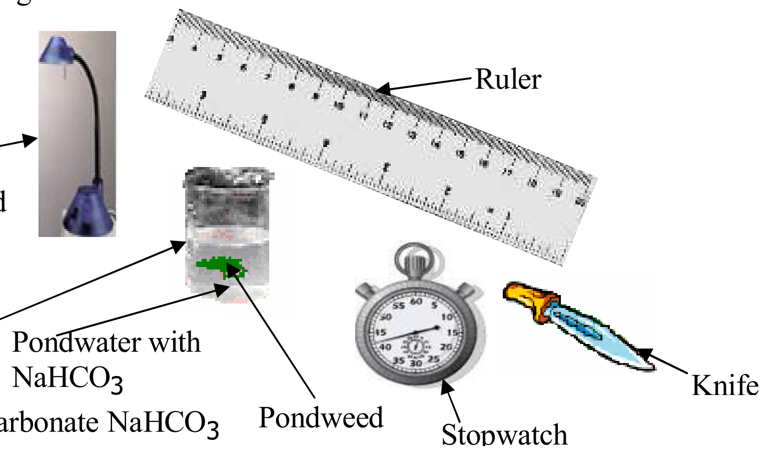
Safety

- Follow lab safety rules
- Keep the lamp away from contact with water
- Be careful with lamp as it will get hot.

In this investigation, I have used Letts GCSE Revision guide to help me extend my knowledge and understanding even further.

Apparatus

- Desk lamp
- Canadian pondweed
- Knife
- Water
- Stopwatch
- Ruler
- Beaker
- Sodium hydrogen carbonate $NaHCO_3$



Method

(Here are the distance (Cm) considered for my main investigation (2Cm, 4Cm, 6Cm, 8Cm, 10Cm, 12Cm and 14Cm)

1. Collect apparatus
2. Fill beaker with a large body of water
3. Cut each end of pondweed as this is where carbon dioxide will escape from and place in water, adding a tiny amount of $NaHCO_3$
4. Make sure hand is not wet and also the switch is off first
5. Connect lamp to switch and then turn on lamp
6. Place plant 2Cm away from light source measuring with ruler and time for one minute, counting the number of oxygen bubbles and record into table (Do the same for the other distance)

(This is just one experiment, repeat from point 6 for second experiment)

Results for my main investigation

Lamp distance (Cm)	**Experiment 1 bubbles per minute**	**Experiment 2 bubbles per minute**	**Average bubbles per minute**
2	**107**	**104**	**105.5**
4	**108**	**95**	**97.5**
6	**78**	**74**	**76**
8	**61**	**61**	**61**
10	**50**	**50**	**50**
12	**45**	**43**	**44**
14	**39**	**23**	**31**

This result shows the lamp distance away from the pondweed and the number of bubbles produced per minute. I also decided to calculate the average bubbles per minute to make it more accurate.

I know that the light intensity is measured in lux. To measure the light intensity, you use the following formula:
$1/d^2$ (d is the distance)
I'm going to work out the light intensity in the table below using the formula above.

d (distance)	**d^2**	**$1/d^2$ Lux (Light intensity)**	**Light intensity in standard index form to the power of -3 ($*10^{-3}$)**
2	4	1/4 = 0.2500	$250*10^{-3}$
4	1	1/16 = 0.0625	$62.5*10^{-3}$
6	36	1/36 = 0.0278	$27.8*10^{-3}$
8	64	1/64 = 0.0156	$15.6*10^{-3}$
10	100	1/100 = 0.100	$10*10^{-3}$
12	144	1/144 = 0069	$6.9*10^{-3}$
14	196	1/196 = 0.0051	$5.1*10^{-3}$

The reason why I have calculated the light intensity in standard index form to the power of -3 is because it will make it easier later on to plot the information on a graph.

I will use this information to plot a graph using the light intensity in standard index form (but however ignoring to the power of -3) with the average number of bubbles.

Considering evidence

While observing the graphs for experiment 1, experiment 2 and the average number of bubbles per minute, I noticed that they all showed a similar pattern: there is a significant increase in the rate of photosynthesis as the distance decreases. On the graph for experiment 1, I can see that when the distance was 8Cm, there were fewer bubbles produced (61 bubbles) than when he lamp distance was at 6Cm (78 bubbles). This pattern is also shown on the graph for experiment 2 and also on the average graph. I believe this is because when the lamp is close to the pondweed more of the pondweeds surface area has light energy shining upon it, which means more photosynthesis occurring per minute.

This also proves my prediction that "as the distance of the light from the plant decrease, the rate of photosynthesis will increase up to a certain point". This is because there is more light energy shining on the surface area when the lamp is closer; therefore greater surface area equals more photosynthesis (greater number of bubbles produced). If light energy is limiting then the rate of photosynthesis slows down intensively. I moved the lam 2Cm each minute and then counted the number of bubbles. As I moved the lamp away from the pondweed, the rate of photosynthesis limited, as shown in my graphs. The scientific knowledge is that plants need light to carry out photosynthesis and produce bubbles of gas, but if light is limiting, then the rate of photosynthesis is also limiting which allows the rate of oxygen bubbles to slow down. Light is needed for photosynthesis to occur, without it photosynthesis cannot happen as light intensity can produce bubbles that occur in the experiment, these bubbles reduce when the amount of light reaching the plant is moved away, which I demonstrated in my experiment.

However, the lamp distance and the number of bubbles was not the best way to investigate how light intensity affects the rate of photosynthesis. This is why I calculated the light intensity and plotted the results with the number of bubbles on a graph.

Looking at the light intensity and the rate of photosynthesis graph, I can state that an increase in light intensity certainly does increase the rate of photosynthesis up to a point. As I expected in my prediction, the relationship between light intensity and the rate of photosynthesis was non-linear. From the graph, there is an increasing exponential line of best-fit. This means that the rate of photosynthesis increased as the light intensity increased up to the light saturation point. This is because photosynthesis is a reaction, which needs energy from light to work, so as the amount of energy available from light increased with the rise in light intensity, so did the amount of oxygen produced as a product of photosynthesis until the light saturation point. As shown on the graph, the rate of photosynthesis started to level off at about light intensity of 25lux. The point where the rate of photosynthesis plateaus can be attributed to the other factors limiting the rate of photosynthesis. As light intensity increases, the rate of photosynthesis is being limited by certain factors such as carbon dioxide and temperature. These factors do not immediately limit the rate of photosynthesis but rather gradually. As light intensity increases further, the rate of photosynthesis is being limited by other factors more and more until the rate of photosynthesis is constant.

Overall, all my graphs and results support my prediction. My idea that the rate of photosynthesis would increase with light intensity up to a point was comprehensively backed up by my results. 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. Here, 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 produced oxygen 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 up to a peak called the light saturation point, after which there is no increase in photosynthesis with increasing light intensity due to the plant being limited by lack of increase in temperature or carbon dioxide.

Evaluation

Although I feel that my experiment was sound overall and supported my prediction, I thought there were many points at which the accuracy was not perfect since I got a few anomalies. As I have already stated, my preliminary experiment was not accurate enough to justify being used as my main experiment, mostly due to the fact that I was relying on all the bubbles being the same size, which they clearly weren't, however many of the smaller inaccuracies also apply to my main experiment.

Firstly, the distance between the light sources and the pondweed were not measured to a very high degree of accuracy, especially when you note the fact that the distance should have been measured exactly from the filament of the light bulb to the centre of the plant. I couldn't control how much light was absorbed by the water and also some of the light might have been reflected when the light hits the beaker. This might have caused the anomalous results.

While performing the experiment, the piece of pondweed did not photosynthesize at a steady rate, for example the result achieved for experiment 1 at a distance of 4Cm was far greater than the amount of bubbles produced in the second experiment at the same distance. While the number of oxygen bubbles was being recorded, the rate at which the plant photosynthesized had increased several times. This may be due to the poor circulation of sodium hydrogen carbonate at the beginning of the experiment. Carbon dioxide may have initially limited the rate of photosynthesis.

A large factor in determining data accuracy is the amount of human error during the experiment. The rate at which oxygen bubbles were being produced by the plant was sometimes so high that I found it difficult to count the amount of bubbles. To improve the accuracy of the results, the readings would have to be taken several more times. The entire experiment could have been performed again and the new results could be combined if the same plant is used.

There are quite a few factors that could affect the anomalous results of my experiment. Some of these are factors that were mentioned earlier and could have changed slightly, i.e. temperature. Or there were other factors that were not initially considered.

Another reason for anomalous results occurring is while performing the experiment, some of the oxygen produced from photosynthesis may have dissolved into the water. Microorganisms living on the pondweed may have even used some oxygen. Some oxygen is also used during the respiration of the plant.

For a more accurate analysis of the collected data, volume of gas should have been measured instead of bubble quantity since the size of bubbles can vary. Using a capillary tube in place of the beaker so that the volume of each bubble could have been measured could have improved my results.

There are also factors affecting accuracy at low light intensities. With low light intensity, the pondweed receives some light energy from background light such as sunlight seeping through curtains or the light from the lamp of another student's experiment. To eliminate most of the background light, the experiment must be performed in a completely dark room

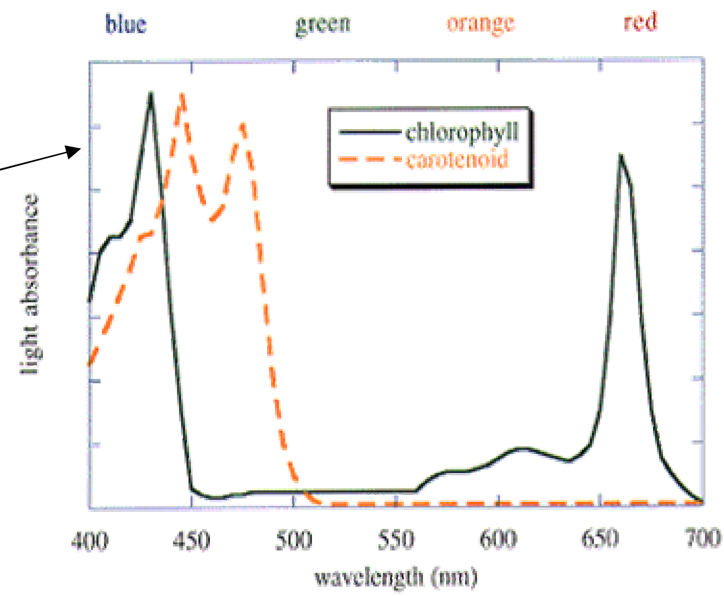
Temperature could have affected the anomalous results. Although I used a large body of water to prevent the lamp heating up the water quickly, I still believe that some of the heat from the lamp could have changed the temperature of the water slightly.

The last inaccuracy, though a small one could have being the timing. I might have started timing each distance a little bit under a second late or ended it one or two seconds late after one minute. This would affect the results because I might have just counted one or two bubbles just after the one minute. This will affect the accuracy of my results.

Overall, I felt that due to the small volumes of oxygen involved, my experiment was not as accurate as it could have been, however I believe it was accurate enough to support and justify my hypothesis and prediction. Improvements could have been made as I have stated, mainly by simply taking the reading for my investigation, maybe every 30 seconds. However, due to practical time constraints in taking the reading for my investigation to time extension, I could not in fact make these adjustments. The other obvious way of increasing the reliability of my results would be to repeat the experiment more than twice and find an overall average result.

To extend my enquiries into the rate of photosynthesis, I could perhaps investigate another variable of photosynthesis. As this investigation was fascinating, I would consider a colour experiment where I would investigate how wavelength of light affects the rate of photosynthesis.

As shown on earlier pages of this investigation, energy used for photosynthesis is provided by light which is absorbed by pigments (primarily chlorophylls and carotenoids). Chlorophylls absorb blue and red light and carotenoids absorbs blue-green light but green and yellow light are not effectively absorbed by photosynthetic pigments in plants: therefore, light of these colours is either reflected by leaves or passes through the leaves.



This is how the experiment would be set up:
I would use basically similar apparatus used in this investigation, but however, a white light would be used because a white light contains all the different light wavelengths. Between the light and the pondweed, I would place a colour filter (colorimeter) which will be connected to a computer. The computer will read the amount of each light wavelength absorbed by the plant.

In the investigation, I would expect the photosynthetic rates of the pondweed would generally follow the absorption spectra of the three primary photosynthetic pigment classes (chlorophylls a and b and carotenoids), with peak rates of photosynthesis occurring under light at the optimum ranges of those spectra. I believed this because these photosynthetic pigments would absorb the light energy and use it to drive the light reactions of photosynthesis, which would in turn produce molecules to drive the Calvin cycle of carbon fixation--and growth.