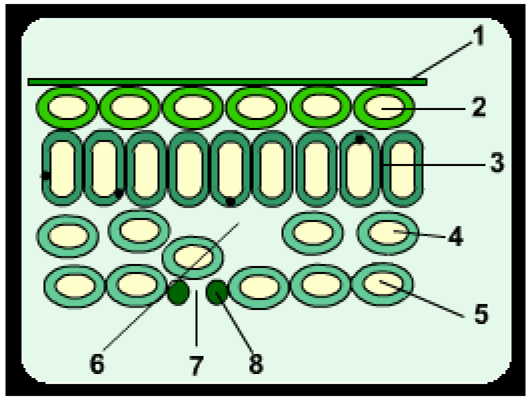
Photosynthesis

Background information

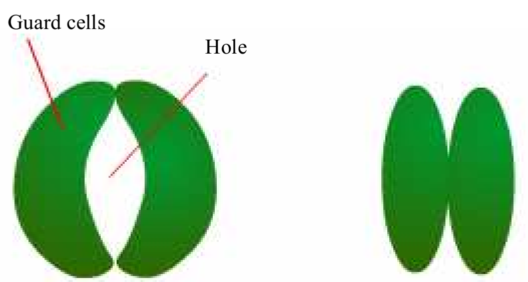
The leaves are the part of a plant where most photosynthesis takes place. If you cut a leaf in half and look at the cut end, it would look like this:



Key:

1. Waxy cuticle: this gives the leaf a waterproof layer, which lets in light.
2. Upper epidermis: provides an upper surface.
3. Palisade cells: contain chloroplasts.
4. Spongy mesophyll: collection of damp, loosely packed cells.
5. Lower epidermis: layer of cells on the lower surface.
6. Air space inside the leaf: allows contact between air and moist cell surfaces.
7. Stoma: a hole in the leaf through which gases diffuse.
8. Guard cells: change shape to close the stoma.

One unique feature of leaves is that they have tiny holes in them to let carbon dioxide and oxygen enter and exit. The hole formed between these cells is called a stoma. A stoma is just a hole. It is controlled by two guard cells, which change shape to either open or close the hole. Something makes water enter the cells by osmosis and so they swell up and change shape, but no one is quite sure of the trigger. The stomata (air holes) on plants are normally open during the day and closed at night. These stomata are found on the undersides of leaves. This is because if they faced the sunlight, some of the plant's precious water could evaporate out of them.



Open stoma Closed stoma

Photosynthesis is the way that plants make their food using energy from sunlight. This is the word equation:

Carbon dioxide + Water —**SUNLIGHT**→ **Sugar + Oxygen + Water**

Plants use the green dye (or pigment) called chlorophyll to pick up the energy from the sunlight. Plants make sugar and use some of it for energy to keep them alive (respiration) but they also use some for growth and repair by making fats and proteins. However, it is not always sunny so plants need to be able to store some of the sugar they make, so they convert it to a storage carbohydrate (starch). Plants could use starch or glucose. Starch is insoluble (it does not dissolve in water) while glucose is soluble. This means that if starch is used, less water is required to keep its food stored. The amounts of water, carbon dioxide, sunlight and temperature can all affect how effectively a plant carries out photosynthesis. The amount of water is effected by how much is taken up through the roots and how much is lost from the leaves. If less water is available in the leaf then photosynthesis will occur more slowly. Similarly, if there is less carbon dioxide around then photosynthesis will occur more slowly. There wont be enough of the fuel (substrate) to get the reaction to work. If there is less sun, which usually means it is cooler too, then there is less energy for photosynthesis and it occurs more slowly. So photosynthesis works best when it is warm and sunny.

Aim

The aim of my experiment is to determine whether or not the intensity of light will affect the rate of photosynthesis in a plant. To do this, I am going to observe Canadian pond weed (Elodea) under varying light intensities. The Elodea will be submerged in water. I will count the amount of oxygen given off in this experiment by counting the number of bubbles produced. I used Canadian pondweed because of its unusual ability to emit bubbles of gas from a cut end, when placed in water.

Introduction

Photosynthesis occurs only in the presence of light, and takes place in the chloroplasts of green plant cells. Photosynthesis can be defined as the production of simple sugars from carbon dioxide and water causing the release of sugar and oxygen. The chemical equation for photosynthesis can be expressed as:

$$\text{Carbon dioxide} + \text{water} \xrightarrow{\text{sunlight}} \text{sugar (glucose)} + \text{oxygen} + \text{water}$$

$$CO_2 + H_2O \longrightarrow C_6H_2O_6 + O_2 + H_2O$$

All plants need light in order to photosynthesise. This has been proven many times in experiments, so it is possible to say that without light, the plant would die. The reason that light intensity does affect the rate of photosynthesis is because as light (and therefore energy) falls on the chloroplasts in a leaf, it is trapped by the chlorophyll, which then makes the energy available for chemical reactions in the plant. As the amount of sunlight (or in this case light from a bulb) falls on the plant, energy is absorbed. This means that energy is available for the chemical reactions, and so photosynthesis takes place. The more light there is that falls on the leaf in the first place, the quicker the rate that the reaction can take place. There are many factors which will affect the rate of photosynthesis, including light intensity, temperature and carbon dioxide concentration. The maximum rate of photosynthesis will be controlled by a limiting factor. This factor will prevent the rate of photosynthesis from rising above a certain level, even if the other conditions needed for photosynthesis are improved. It will therefore be necessary to control these factors throughout the experiment so as not to let them affect the reliability of my investigation into the effect of light intensity.

Predictions

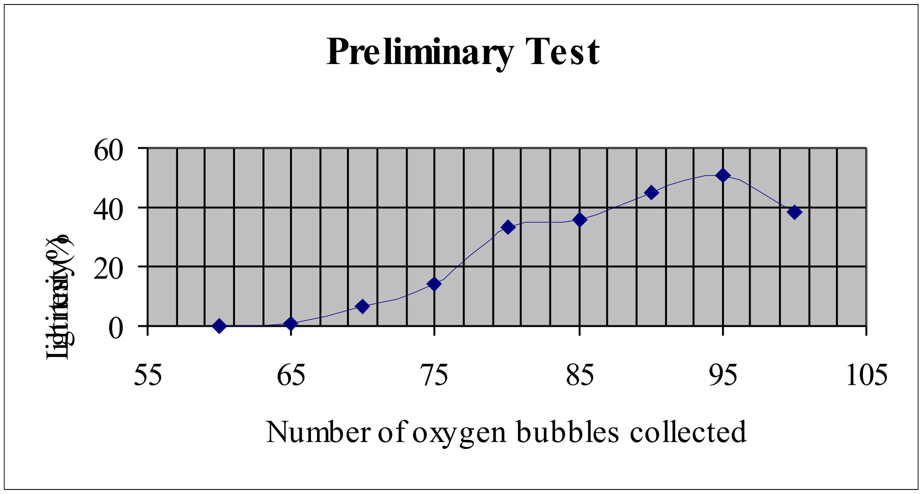
I predict that as the intensity of light increase, so will the rate of photosynthesis. I also predict that if the light intensity increases, the rate of photosynthesis will increase at a proportional rate until a certain level is reached, and the rate of increase will then go down. Eventually, a level will be reached 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 temperature.

Preliminary work

Initially, to determine a suitable range of levels of light intensities at which to record results for my experiment, I did a preliminary investigation in which I recorded the number of bubbles of oxygen given off in a given time at various light intensities. To alter the light intensity, I placed a lamp at various distances from the plant. I also therefore needed a way of accurately measuring the light intensity, and I did this using a light intensity monitor. I obtained the following results:

Light intensity (%)	Number of oxygen bubbles collected
100	38
95	51
90	45
85	36
80	33
75	14
70	7
65	1
60	0

Although this is a very quick, simple and efficient way of obtaining an idea of the trends for the graph, and the boundaries for the measurements, this experiment was not in itself in my opinion accurate enough to be the basis of my main experiment. This lack of accuracy was mainly due to the fact that by simply counting the bubbles, I was relying on each bubble being exactly the same size, which they clearly were not. The preliminary experiment will give me a best fit curve to which I can compare my main graph, and also points at either end of my results at which it is clear to see light intensity has little or no effect. Here, it was in fact at a light intensity of around 95% when it seems that another factor such as temperature or carbon dioxide concentration has become a limiting factor. In my main experiment, it will not be necessary to take readings above this point. It also shows that while my outer limits are justified, it will be better to take more readings between the current light intensity values of around 60 – 95%. I will take readings at 60%, 62.5%, 65%, 67.5%, 70%, 72.5% … This way I will obtain more results between an accurate value scale. Here are my results from my preliminary experiment:



Method

Input variables
Light intensity – This is to be varied by increasing and decreasing the distance from the light source to the plant
Output variables
Volume of oxygen (rate of photosynthesis) – This is to be measured by finding the number of bubbles of oxygen produced in a 30 seconds.
Carbon dioxide concentration – This can affect the rate of photosynthesis, since if there is too little CO_2, it can become the limiting factor. In this case, as long as the experiment is done over a short period of time, the amount of carbon dioxide used up by the plant will not be sufficient enough to cause the carbon dioxide concentration to become the limiting factor. If my experiment were to be performed over a longer period of time, this would become a problem.
Water availability – Water is also required in the photosynthesis reaction, and when it is lacking, the plants' stomata close to prevent further water loss. This closing of the stomata cells also leads to little carbon dioxide being able to diffuse through. Clearly, in a water plant, (like the pondweed) as long as the plant is fully submerged in water at all times, this will not be a problem.
Temperature – Enzymes are used in the photosynthesis reactions of a plant. Therefore, temperature will increase the rate of photosynthesis, until a point at which the enzymes weaken and work at a slower rate. I am going to perform the experiment at 22 degrees, checking the temperature frequently in case the heat given off from the light should slightly raise the temperature, in which case I shall simply refill the beaker with more water after each experiment.

Apparatus list

- Desk lamp
- Elodea pondweed
- Clamp
- Water
- Thermometer
- Test-tube
- Beaker
- Cold water
- Stopwatch
- Light intensity meter

Cut a stem of Canadian pondweed of about 7cm in length. Fill a test-tube with water, and place it in a clamp. Then place the test tube into a beaker of cold water. Insert a thermometer into the beaker, and record the temperature at the beginning and end of each experiment, (as a precaution against a significant unexpected rise in temperature). Set up a lamp at a set distance from the plant, ensuring that this distance is from the filament of the lamp to the actual pondweed, rather than the edge of the beaker. The light intensity must be measured in the same way as described in the preliminary experiment. When bubbles are being produced at a steady rate, start the stopwatch and count how many oxygen bubbles are produced in 30 seconds. Repeat this experiment three times for accuracy. Following the aforementioned method, I obtained these results:

Light intensity (%)	Number of bubbles counted		
	Test 1	Test 2	Test 3
95	52	50	50
90	47	48	46
85	37	39	39
80	35	32	33
75	12	13	10
70	4	2	3
65	1	0	2
60	1	0	0

From these results, I have worked out one set of average results and drawn a graph to show them. The results are rounded up to integers because the "number of bubbles counted" is discrete data (ie – "4 and a half bubbles" would not be appropriate).

Light intensity (%)	Average number of bubbles counted
95	51
90	47
85	38
80	33
75	12
70	3
65	1
60	0

*******Analysis*******

*****My graph was in the form of a best-fit curve. I drew it as a curve rather than a straight line because of the clear pattern of the points. This meant that the rate of photosynthesis increased as the light intensity increased. This was 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.

My graphs showed that the relationship between the light intensity and the rate of photosynthesis was non-linear, as both graphs produced a best-fit curve. However, as I expected in my hypothesis, it does appear that for the very first part of the graph, the increase in rate is in fact proportional to the increase in light intensity (i.e. a straight line) and I can show this by taking some readings from the graph:

Results from graph…

From these results, I am able to say that an increase in light intensity does certainly increase the rate of photosynthesis. The gradual decrease in the rate of increase of the rate of photosynthesis (the shallowing of the curve) can be attributed to the other factors limiting the rate of photosynthesis. As light intensity increases, the photosynthetic rate 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, so the rate of photosynthesis is being limited by other factors more and more, until the rate of photosynthesis is constant, and so is almost certainly limited in full by another factor.

Overall, both graphs and my results support my predictions fully. My idea that the rate of photosynthesis would increase with light intensity 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 synthesised 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 that my experiment was sound overall, I thought there were many points at which the accuracy was not perfect. As I have already stated, my preliminary experiment was not accurate enough to justify being used as my main experiment. This was 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 Canadian 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. It is possible here to find a percentage error. I estimate that the error could have been up to 0.5cm and I will find the percentage error for the largest and smallest reading using this estimate:

Percentage error = possible inaccuracy

total reading

% error	distance
10	5cm
1	50cm

*Percentage error is just how much your guess was off from the actual value. The formula is:

|estimate - actual|/actual * 100%
[That is: the absolute value of (the estimate minus the actual) all divided by the actual, all multiplied by 100%.]*

It is clear to see that the percentage error is much less for the larger distances. Although I was not actually using the distances as part of my results, I used them as a marker for where the lamp was placed each time, as I assumed that the light intensity would be the same each time at a particular distance. Therefore, any inaccuracies in measuring the distances, i.e. if a distance was slightly different when doing the actual experiment from the distance at which I earlier measured the light intensity, an error would ensue.

The second major inaccuracy was in measuring the volume of oxygen given off.

When reading the syringe there could have been an error of 0.25mm, and again it is possible to find a percentage error.

% error	volume
3.57	7ml
50	0.5ml

For the smallest volumes this is clearly a massive error, and to improve this, it would be necessary to do the readings over a longer period of time, therefore increasing the volumes, and in turn reducing the percentage errors.

Another error would have been due to background light in the vicinity. We tried to reduce this error by closing all blinds in the laboratory, but due to practical reasons, we could not all perform the experiment in a separate room, and we therefore experienced light pollution from other student's experiments. This would have had a very marginal effect on my results as a whole, but to 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 earlier described, temperature has a very noticeable effect on the rate of photosynthesis, and so any increase in the temperature of the pond water would have had serious effects on the accuracy of my results. To ensure this did not happen, I monitored the temperature of the water before and after every reading, to check that the temperature did in fact not rise. It turned out not to be a problem, as over the short period of time taken by my experimental readings, the temperature did not rise at all. However, if I were to extend the time of my experiment to 5 minutes for each reading for example, which would have the effect of reducing other percentage errors, I would have to find some way of keeping the temperature constant. One way of doing this would be to place a perspex block between the lamp and the plant, which would absorb most of the heat, while allowing the light energy to pass through.

As I mentioned in my planning, carbon dioxide concentration could have been an error in the experiment. However, I feel that due to the short period of time taken there is very little chance that the concentration would ever have been so low as to become the limiting factor. Again if I were to carry out the experiment over a longer time period, it would have been necessary to add sodium hydrogen carbonate to the water to increase the carbon dioxide concentrations.

The last inaccuracy, though a small one, was in the time keeping. The main problem here was in when to begin the minute. If for one reading, the minute was started just after one bubble had been produced, and in another reading it was just before, this could have had a negative effect on the accuracy of my results. I therefore ensured that in each case I started the stopwatch just after a bubble had been produced, thus heightening the accuracy.

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 hypotheses. Improvements could have been made as I have stated, mainly by simply increasing the time taken. However, due to practical time constraints in taking the readings for my investigation, and some consequential problems relating 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 take many repeat readings and find an average.

To extend my enquiries into the rate of photosynthesis, I could perhaps try to link in some of the other limiting factors to the same experiment, as well as investigating them in their own right. It could also be interesting to explore the effects of coloured lights on the rate of photosynthesis, which could lead to the question of whether or not other types of light, such as fluorescent lights or halogen lights, would have a different effect on the rate of photosynthesis.