Investigation To Find The Effect Of Temperature On The Rate Of Photosynthesis Of Elodea

Hypothesis

I believe that as the temperature rises, the rate of photosynthesis will also increase. That is until the plant reaches its optimum temperature and then the rate of photosynthesis will decrease.

Photosynthesis is the process necessary for plants as this is how they obtain their food. The formula for this process is- 6CO2 + 6H2O □6H1206 + 602. The rate of photosynthesis are affected by these factors: concentration of carbon dioxide, light intensity and temperature.If one of these factors increase, the rate of photosynthesis will increase but only to a certain point. The rate of photosynthesis could still increase but not because of an increase in that same factor. Another factor has to increase for the rate to increase. The factor that restricts the other two factors from increasing the rate of photosynthesis is called the limiting factor.

For glucose to be made in photosynthesis, water is split into hydrogen and oxygen molecules by the energy absorbed from the sun. The hydrogen then has to combine with the carbon dioxide to produce glucose. If this was left on its own, the hydrogen would eventually combine with the carbon dioxide but it would take a long time. That is why a catalyst is needed to quicken the process.

Enzymes are the catalyst used for the anabolic reaction. Enzymes work by colliding with the hydrogen and carbon dioxide. It is shaped to only accept hydrogen and carbon dioxide molecules. A rise in temperature provides more heat energy, which the enzymes absorb to work faster. They work faster by colliding more frequently. Because of that, it produces more glucose quickly. As with all enzymes, it has an optimum temperature and after that, the enzymes denature. It cannot act as a catalyst anymore and the rate decreases.

Apparatus

Photosynthometer
Elodea
Beaker of water
Lamp
Ice
Hot water
Thermometer

Method

The independent variable of the experiment was temperature. The dependent variable was air. Other factors that we knew that affected photosynthesis (carbon dioxide and light) were kept the same. This was done by placing a lamp 10cm away from the beaker throughout the whole experiment. We assumed that the water in the beaker contained the same concentration of carbon dioxide throughout the whole experiment. We had to be careful with the lamp as it was electrical and we were keeping it near water.

We cut a piece of elodea and put it in a beaker of water, with the cut end kept up by anchoring it with a paperclip. We changed the independent variable (temperature) by changing the temperature of the water. A thermometer was used to measure the temperature of the water. We changed the temperature of water by either adding hot water to warm it up or adding ice to cool it down. We obtained the hot water from by boiling the water in a kettle so we knew it was warm. This was safer than running it from a hot water tap and using our hands to find out if it was warm enough yet.

We measured the dependent variable (air) by using a photosynthometer, with a tubing of 1mm diameter, to measure the volume of air given off by the elodea. From the pilot study, we learnt we had to keep the tubing of the photosynthometer in the water otherwise an air bubble would form in the tubing, presenting unfair results. We measured the volume of air by pulling the syringe back and measured how much more the air bubble has increased in length using the rule on the tubing.

We also learnt from the pilot study that we had to start the elodea photosynthesising straight away to make the best of time. The pilot study showed that a range of 15°C to 30°C would be suitable to use. We needed at least five different variables to be able to obtain a suitable conclusion from the results. We also needed to get two replicates of the results to show any anomalous results and for averages.

Results

A Table To Show The Raw Results Of The Length Of An Air Bubble Containing Oxygen-Enriched Air Produced At Varying Temperature By Elodea With A Lamp 10cm Away From The Elodea

Length/mm
Temperature/°C 1st reading 2nd reading 3rd reading Average reading
17 21 23 25 26 30 0.50 1.00 2.00 3.00 5.00 0.50 0.30 1.50 1.00 1.50 4.00 0.25 0.30 1.00 1.50 1.50 3.00 0.50 0.37 1.17 1.50 2.00 4.00 0.42

The readings and averages are rounded to 2 decinal points.

A Table To Show The Volume Of Oxygen-Enriched Air Produced At Varying Temperatures By Elodea With A Lamp 10cm Away From The Elodea Worked From The Raw Results

Volume per minute/ mm3/minute
Temperature/°C 1st reading 2nd reading 3rd reading Average reading
17 21 23 25 26 30 0.39 0.79 1.57 2.36 3.93 0.39 0.24 1.18 0.79 1.18 3.14 0.20 0.24 0.79 1.18 1.18 2.36 0.39 0.29 0.92 1.18 1.57 3.14 0.33

Results were worked from the raw results by applying the using the formula for working out the volume of a cylinder. The formula for working out the volume of a cylinder is pr2h. The lengths collected are h and the radius is half the diameter of the tubing (0.5mm). So the lengths collected were multiplied by the square of 0.5 (0.25) and by p . The results above are rounded to two decimal places.

Conclusion

As the temperature rose from 17°C to 26°C, the rate of photosynthesis rose from producing an average of 0.29mm3 per minute of oxygen-enriched air to 3.14mm3 per minute of oxygen-enriched air. Because the temperature was getting higher, the enzymes were absorbing more heat energy. Therefore, they were moving faster and were reacting quicker during these temperatures.

It stopped rising after 26°C and the rate of photosynthesis fell to an average of 0.33mm3 per minute. This is because after the enzymes reach their optimum temperature, they become denatured. Their shape is changed and they can no longer perform their function, which is in this case, combining hydrogen and carbon dioxide. This meant that the optimum temperature for the enzymes in the elodea is between 26-30°C.

The rise in the rate of photosynthesis until the optimum temperature that afterwards fell, supported my hypothesis.

Evaluation

The replicates did give roughly the same readings so the results are reliable overall e.g. when the temperature was 17°C, the 1st reading was 0.39mm3 per minute and the second and third

was 0.24mm3 per minute.

There was an anomalous result when the temperature was 25°C. The first reading had the rate of photosynthesis as 2.36mm3 per minute whereas the other two readings were 1.18mm3 per minute, which is half the first reading. The first reading is almost twice the average. This was the room temperature and therefore the first measurement of the elodea that we took. I believe it was because while we were waiting for the plant to start photosynthesising at a regular rate, it could have already started to photosynthesise. We did not take a measurement of the air at the beginning of the experiment and so that was likely to have been added to the first measurement, making the experiment unfair. If I were to repeat this experiment, I would make sure that the amount of air in the photosynthometer was measured.

I am satisfied with the range of the results we covered but I do believe that the temperatures we measured could be more chosen with more reason instead of randomly picked in a given range. I would have also liked to have made more measurements to find the optimum temperature of the plant. There was enough evidence to draw a suitable conclusion.

The equipment used was more reliable than counting bubbles but there were still inaccuracies in the experiment. Sometimes the air given off from the elodea, did not go into the funnel and is not recorded in the experiment. This could lead to underestimating the rate of photosynthesis.

The plant was respiring in between the changing of the temperatures. This meant that air was being produced and was not exactly dependent on the temperature. This would explain why most of the first readings were higher than the second and third readings.

It was very unlikely that the bubbles were pure oxygen as we know that the plant also respires all the time. If I was improving the experiment, I would use an oxygen probe to measure the amount of oxygen and it would be more accurate than reading it off a rule.

I would like to find the effect of pH on a plant. As pH affects the rate of enzymes, it should also affect the rate of photosynthesis.

Rate of Photosynthesis

Aim: To investigate a factor that affects the rate of photosynthesis.

Outline: A piece of pond weed will be cut and placed into a beaker containing water and sodium hydrogen carbonate. A lamp will be shined on to the pond weed and the amount of bubbles released from the plant will be counted. The lamp will be adjusted to different distances from the plant to try and obtain different results.

Photosynthesis Equation:

$6CO_2 + 6H_2O$ light energy & chlorophyll $C_6H_{12}O_6 + 6O_2$

Variables:
Experimental Variable- Light intensity is to be the variable explored in this investigation. Light intensity can be varied by increasing or decreasing the distance from the light source to the plant.

Fixed Variables-
Light Wavelength (color)- Light energy is absorbed by pigments in the leaf such as chlorophyll. Chlorophyll easily absorbs blue light, in the 400-450 nm range, and also easily absorbs red light in the 650-700 nm range. Chlorophyll does not absorb green light or yellow light effectively but tends to reflect them, decreasing the amount of light absorbed and decreasing the rate of photosynthesis. Why the rate of photosynthesis increases or decreased from the amount of light energy absorbed is what is being investigated in this experiment. The light color can be fixed by using the same lamp throughout the experiment.
Carbon Dioxide- CO_2 concentration can affect the rate of photosynthesis since the more CO_2 in the air, the more CO_2 that can diffuse into the leaf. This variable can be fixed by adding a fixed amount of sodium hydrogen carbonate to the beaker and plant. The experiment should also be completed in one session and under two hours so the plant does not use up a significant percentage of the CO_2.
Water- Water is required in the photosynthetic reaction. When plants lack water, their stomata close to prevent further water loss. At the same time, closing the stomata cells doesn't allow CO_2 to diffuse into the leaf. Water is also therefore, linked to the carbon dioxide factor. Water can be kept a constant by keeping the same amount of water in the beaker.
Temperature- Enzymes are used in photosynthesis and the respiration of the plant. Therefore, increasing the temperature will increase enzyme reaction and the photosynthetic rate until a certain point is reached when the enzymes denature. The temperature can be kept somewhat a constant by performing the experiment in one session, when the air temperature shouldn't change enough to affect water temperature. A transparent glass block will also be placed in front of the lamp to retain some of the heat from the lamp.
Plant- Different species plants have different photosynthetic rates due to the different leaf structures of the plants. Even plants of the same species may have slightly different rates of photosynthesis since there may be more or less chlorophyll in the leaves to absorb light. The size of the plant is also important since this would affect the amount of surface area for gas exchange. The only solution to controlling this variable is by using the same plant throughout the experiment.
Limiting Factors- Light, carbon dioxide, temperature, and chlorophyll are all limiting factors, meaning that even when there is surplus of every other variable, the rate of photosynthesis

will be limited by the limiting factor until there is an optimal amount of the limiting factor to increase the rate of photosynthesis further. Otherwise, the rate of photosynthesis can no longer increase.
Prediction: I predict that increasing the light intensity will increase the rate of photosynthesis at a proportional rate where LI is inversly proportional to 1/d2 when LI= light intensity and d= distance (from light source to plant). This is true to a certain point until another factor is limiting the rate of photosynthesis.

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 center, 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 the experiment. The greater the light intensity, the more light energy that can be transferred and harnessed to 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.

Method:

1. Set up the apparatus as shown in the diagram above but leaving out the pond weed, funnel, test tube, water, and the sodium hydrogen carbonate.
2. Fill the beaker with 450 cm3 of water and 50 cm3 of NaHCO3.
3. Select 1 or 2 pieces of pond weed each roughly 5-10 cm long and cut off the stems.
4. Place the pond weed in the beaker and secure the funnel upside down over (on top of) the pond weed using the plasticine.
5. Place a water-filled test tube upside down and over the funnel (see diagram).
6. Place the ruler so that the "0" measurement is aligned with the side of the beaker. (distance measured from side of beaker to edge of light bulb)
7.) Place the lamp directly in front of the plant so that it is 0 cm away from the beaker. 8.) With the light shining on the plant, record the number of bubbles emitted in a 1 minute duration. Switch off the lamp and wait for another minute before taking another reading.
9.) Take 3 readings at the current distance and move the lamp 5 cm further away from the plant.
10.) Repeat steps 8 and 9 until 3 readings from at least 5 intervals of 5 cm have been taken.
11.) Proceed to the data analysis stage.

Results:

Distance (cm)	Light Intensity (LUX)	Bubbles per Minute			Average bubbles/minute
		1	2	3	
0 (off scale)		240	249	251	246.7
5	11,000	201	222	214	212.3
10	5,800	183	185	188	185.3
15	3,570	154	152	158	154.7
20	2,320	128	118	124	123.3
25	1,780	93	88	90	90.3
30	1,320	67	65	70	67.3
35	1,050	53	50	48	50.3
40	850	38	38	37	37.7
45	690	26	25	24	25
50	580	17	17	18	17.3

The temperature of the water stayed a constant at about 29.5O C throughout the experiment.

Conclusion:
From the results that I have gathered I can state that an increase in light intensity certainly does increase the rate of photosynthesis. As was also expected in my prediction, the relationship between light intensity and the rate of photosynthesis was non-linear. From both graphs there is a best-fit curved line. This means that the rate of photosynthesis increases at an exponential rate.
However, my prediction that light intensity is inversely proportional to the distance squared did not fit into my results perfectly. The rule existed but there was often quite a large margin of error.
When measuring light intensity in terms of distance, the greater the distance, the slower the rate of photosynthesis. While the rate of photosynthesis was decreasing, the rate at which it was decreasing at was also decelerating. This is where the line in graph 1 shallowed.
When measuring the light intensity in terms of LUC, the greater the distance, the slower the greater the rate of photosynthesis. While the photosynthetic rate increased, the rate at which it increased was decreasing. This is where the line in graph 2 shallows.
The shallowing of the line in graph 1 can be explained by the fact that light intensity is inversely proportional to the distance squared. This means that as distance increases the light intensity decreases at an exponential rate. If light intensity decreases exponentially, photosynthetic rates that depend on light intensity also decreases exponentially. The line in graph 1 would eventually reach "0" where photosynthesis stops as light intensity limits this rate.

The shallowing of the line in graph 2 is due to other factors limiting the rate of photosynthesis. These other factors do not immediately limit the rate of photosynthesis but rather gradually. As light intensity increases the photosynthetic rate is being limited by certain factors such as carbon dioxide and temperature. As light intensity increases further, these factors limit the rate of photosynthesis even more until photosynthesis is completely limited and the graphed line become horizontal. This is when photosynthesis is being carried out at a constant rate.
The reason that a "f 1/b2 did not apply was due to the apparatus used. The lamp that I used had a cover that directed the light energy somewhat. The light energy did not spread out as much as a plain light bulb with no cover. The distribution of the light energy was more concentrated, changing the gradient of the graph.

Evaluation:
Overall, I would state the experiment as a success since my predictions were supported by my results. This is important in reflecting success only if my prediction was sensible and logical. Just as important is where the experiment was not a success and why. This photosynthesis investigation was probably not performed as accurately as it could have been due to some controllable and uncontrollable conditions. Some mistakes can be corrected.
While performing the experiment, the piece of pond weed did not photosynthesize at a steady rate, even when the distance from the plant to the light source was kept a constant. The second reading at 0 cm was far greater than the first reading at 0 cm. While the number of oxygen bubbles was being recorded, the rate at which the plant was photosynthesizing 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. The readings at 0 cm and 5 cm were repeated many times until the rate of photosynthesis had begun to settle. From then on, there were no more similar problems during the experiment. To make sure that the there
The negative effects from this problem may be inaccurate data for some readings. These would show up on my graph. However, there seemed to be few anomalies than was expected when the experiment was being performed. Almost all readings were in correlation with each other and all of the anomalies were in the high photosynthetic rate end of the results. This was when the distance from plant to light source was 0 cm or only 5 cm.
A large factor in determining data accuracy is the amount of human error during experiments. The rate at which oxygen bubbles were being produced by my plant was so high that I found it difficult to count the amount of bubbles. I estimate a margin of error of at least 3 bubbles for each reading taken. 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. But the photosynthetic rate of the same piece of pond weed would eventually decrease over time anyway. Repetitions would, however, improve the overall reliability of the results.
There are quite a few factors that could affect the results of my experiment. Some of these are

variables that were mentioned earlier and could not be controlled, or they were variables that were not initially considered.

While performing the experiment, some of the oxygen produced from photosynthesis may have dissolved into the water. Some oxygen may have even been used by micro-organisms living on the pond weed. The amount of oxygen dissolved or used by microbes is probably insignificant to my results since the degree of accuracy at which I measured was not high enough. Some oxygen is also used during the respiration of the plant. But since only bubbles were counted, the volume of bubbles was not as important. But to volume of oxygen produced is important, since it was volume in terms of bubbles that were measured. As the rate of photosynthesis decreased due to a decrease in light intensity, the size of the bubbles produced also became smaller. This change in bubble size was no accounted for when the results were analyzed. For a more accurate analysis of the collected data, volume should have been measured instead of bubble quantity since the size of bubbles can vary. Using a capillary tube in place of the test tube so that the volume of each bubble could have been measured could have done this.

During the high intensities I had experienced counting difficulties of the bubbles being produced. There are also factors affecting accuracy at low light intensities. With low light intensity, the pond weed 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 all background light, the experiment must be performed in a completely dark room. Even then, some of the light from the lamp in my experiment would reflect of the table and reach the plant though this amount of light is probably insignificant in affecting the rate of photosynthesis.

Temperature was also another factor that was controlled by the lamp being used. Even though a glass block was used in front of the lamp to prevent some heat from reaching the plant, not all the heat can be blocked. The extra heat, however, did not affect the temperature of the water, which stayed at between 290 and 300 C.

The method of the experiment could probably also be improved to obtain more reliable results. As already mentioned, the a capillary tube should be used in place of a test tube to accurately measure the volume of the oxygen produced. Due to the high rates of photosynthesis of the pond weed, readings should be taken within shorter time periods. I had originally chosen to count the number of bubbles in one minute but this produced miscounts in the readings. If during a repeated experiment, counting bubbles is still used, there is a smaller chance for human error when counting within a smaller time frame. If the capillary tube option was to be chosen, volume should be measured for a smaller time frame to reduce the overall time to complete the experiment. Also, during high rates of photosynthesis, it would still be difficult and impractical to measure the volume of oxygen produced for a long duration.

Due to the nature and convenience of the experiment, it could be easily modified to investigate another variable of photosynthesis. Since sodium hydrogen carbonate ($NaHCO_3$) is used to provide the pond weed with carbon dioxide. The amount of CO_2 could be varied by

performing the experiment with different volumes of NaHCO3. The plant would be kept at a constant distance from the lamp and a constant volume of water would be added to the sodium hydrogen carbonate. Another experiment using almost identical apparatus would be to vary the color of the light the plant absorbs. This could be varied by using translucent color filters in front the lamps. Since light wave length has already been identified as a variable of photosynthesis, it would be interesting to actually test it. The only problem of this experiment is that there is no way to define or "measure" the color of light. Wave length would be a solution but this cannot be measured with available equipment. We only have a general idea of how to class colors. Because of this, the colored light experiment should not be taken as seriously as light intensity or carbon dioxide.

photosynthesis

PHOTOSYNTHSIS INFORMATION:

The Nature of Light
Light behaves both as a wave phenomenon and as discrete particles of energy called photons. If we look at light as a wave phenomenon, we can assign it a wavelength (the distance from one peak of the wave to the next) and an amplitude (the distance the wave oscillates from its centerline). Different wavelengths of light have different characteristic energies and properties. Light can also travel at various speeds in different media, producing a frequency at which the wave travels. The energy contained in a wave of light is related to its frequency.

Where E is energy, h is Planck's constant Energy = (6.626196 * 10^-34 Joule-seconds), and c is the speed of light. Short wavelengths have high energies and long wavelengths have lower energies.
Pigments
How is light captured by living things? Molecules, when struck by a wave or photon of light, reflect some of its energy back out, or it can absorb the energy, and thus enter into a higher energy or excited state. Each molecule absorbs or reflects its own characteristic wavelengths of light. Molecules that have evolved to absorb wavelengths in the visible region of the spectrum very well are called pigments.
Absorption and Action Spectra
An absorption spectrum for a particular pigment describes the wavelengths at which it can absorb light and enter into an excited state. The following diagram represents the absorption spectrum of pure chlorophylls in solution:

An action spectrum, on the other hand, describes the efficiency of a particular molecule at acheiving its purpose in absorbing light; this measurement shows what wavelengths of light

the molecule can trap to conduct photosynthesis. And action spectrum closely follows an absorption spectrum for a particular pigment because the molecule has to be able to absorb light to enter into its excited state and pass the energy along.
Chlorophylls and the Accessory Pigments
Chlorophyll is a generic name for green pigments in plant cells....a substance that absorbs visible light primarily in the red, violet and blue regions of the light spectrum. There are several kinds of chlorophyll with chlorophyll a being the most important for light dependent reactions in the complex photosynthesis processes. Chlorophyll a and b exist in plastids in cells of higher plants while chlorophyll c,d and e are present only in algae. Photosynthesis is the process of converting light energy into chemical energy which can only be performed by plants. All life on earth depends upon the ability of plants to photosynthesize simple sugars which are the basic source of food from which all other forms of food originate.
A chlorophyll molecule is made up of carbon and nitrogen atoms joined in a complex ring with an atom of magnesium located in the center of the ring. The molecule has a long chain of 20 carbon atoms making up an alcohol "tail" attached to the ring. Each kind of chlorophyll may vary somewhat in its molecular structure giving it slightly different chemical and physical properties.

Chlorophyll appears to have three functions:
It serves as antennae to absorb light energy. In this process it becomes "excited" (it produces electrons that exist beyond their normal "ground" state and are in a "charged"condition, so to speak, ready to move elsewhere as a source of electrical energy.
Chlorophyll transfers H+ electrons by a process known as resonance transfer across thylakoid membranes to P700 and P680 type chlorophyll a molecules.
Chlorophyll, with the aid of enzymes, converts light energy into chemical energy by a complex series of processes of oxidation involving loss of electrons. In these processes carbon dioxide and water are converted to glucose and oxygen.

aim

I aim to investigate the effects of the quantity of light and thus the light intensity on the rate of photosynthesis in Elodea.

background

Photosynthesis is the production of food compounds from carbon dioxide and water by green plants using energy from sunlight, absorbed by chlorophyll ie. photosynthesis is how plants feed.

lightlightlil

$6CO_2 + 6H_2O \quad C_6H_{12}O_6 + 6O_2$

Raw materials Products

ie. Green plants make organic substances from inorganic substances.

In order to keep the equation for photosynthesis simple, glucose is shown as the only food compound produced. However, this does not mean that glucose is not the only food compound produced.

The process of taking in and giving out gases is known as gaseous exchange. When green plants photosynthesise, they take in CO_2 and give out O_2. This only happens in daylight when light is available as an energy supply. The exchange of gases in green plants in light is the opposite of that of animals; however this does not mean that green plants do not respire. During daylight, plants photosynthesise and respire at the same time, hence all CO_2 produced by the plant during respiration is transformed into O_2 and food (and thus energy) for the plant. It is only when the rate of photosynthesis is greater than the rate of respiration that CO_2 will be taken in and excess O_2 given out.

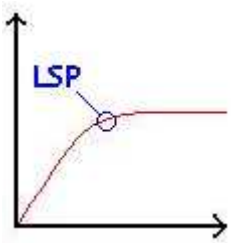
ie. In darkness O_2 is taken in and CO_2 is given out - there is no p/s; in dim light the rate of respiration and p/s is equal - there is no gaseous exchange with the air; in bright light however p/s is faster than respiration and thus O_2 is given out - CO_2 is taken in to use for p/s and the CO_2 made from the plant's respiration is also used to make O_2.

ie. The more light (the higher the light intensity), the greater the rate of p/s - unto the LSP [see below].

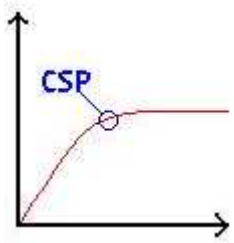
If a plant is given plenty of sunlight, carbon dioxide and water, the limit on the rate of p/s is the ability of the plant to absorb these materials and make them react. (eg. total number and capacity of chloroplasts and the physical limitation of carbon dioxide diffusion.) Most of the time plants DO NOT have an unlimited supply and so the rate of p/s is not as high as it might be.

Blackman's Law states that:

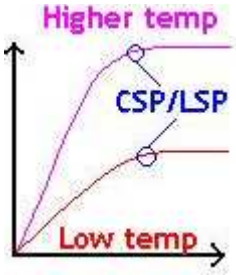
"The factor in least supply will be the limiting factor."



As the light intensity (LI) increases, the rate of p/s increases, until the plant is photosynthesising as fast as it can - the LSP - Light Saturation Point. When the LSP is reached, plants cannot photosynthesise any faster, even when the light gets brighter. From this point on, according to Blackman's Law, the factor in least supply will be the limiting factor ie. either CO_2, H_2O or temperature will be the limiting factor.



As the amount of CO_2 available increases, the rate of p/s increases, until the plant is photosynthesising as fast as it can - the *C*SP - CO_2 Saturation Point. If both CO_2 and light supply are increased together, the rate of p/s will level out. *H*enceforth it is limited, according to Blackman's Law, by the factor in least supply, either H_2O or temperature. however there is a physical limitation of the carbon dioxide diffusion and the plant's sunlight absorption.



At a lower temperature, the rate of p/s is increasing with increasing LI or CO_2 availability, but the LSP or *C*SP is quickly reached. At a higher temperature, the rate of p/s increased further and reaches the LSP / *C*SP slower. Thus we can se that temperature affects the rate of p/s - it is higher at higher temperatures.

From this information, one can see that if one wants to investigate solely the effect of the quantity of light on *E*lodea, one must keep both the amount of CO_2 and the temperature constant.

Light intensity will decrease as the distance between the light source and the object increases, and vice versa.

Thus the relationship between LI and distance can be described as

1 This value will be very small; multiplying the LI 1000

LI = ---- by 1000 makes the LI a more 'workable' number. LI = ------

D^2 D^2

ie. Light intensity is inversely proportional to the square of the distance

Now, I must use this information to make a hypothesis and a plan for the experiment.

hypothesis

I believe that as the LI is increased, the rate of photosynthesis will increase fairly constantly as long as the other limiting factors of p/s are kept constant. This is because increasing the LI (unto the LSP) causes an increase of the rate of p/s, until the plant is photosynthesising as fast as it can, as long as changing the LI is the only variable of the experiment. If there are other variables at the same time as the varying light intensity, this will affect the rate of photosynthesis, and prevent the experiment from being a fair test.

planning

The apparatus used will be as follows:

Clamp stand etc

Beaker (Water bath)

Boiling tube

0.5% Na^+ HCO_3^- solution

*E*lodea Candensis specimen

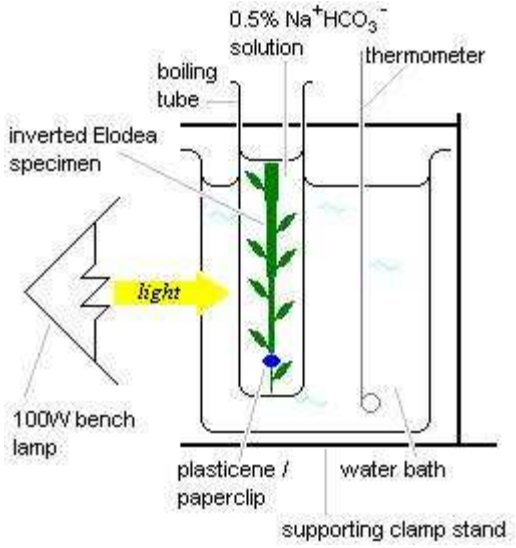
*E*lectric bench lamp with 100W filament bulb

Thermometer

Plasticene / Blu-Tac / Paperclip

Stopwatch

The apparatus will be set up as follows.



The water bath is used to keep the temperature constant - the water bath absorbs the heat from the lamp and thus prevents the *E*lodea specimen from photosynthesising at a faster rate due to temperature increase. The $Na^+HCO_3^-$ releases a constant supply of CO_2 for p/s. The *E*lodea specimen is inverted so that the CO_2 can be released more easily - the CO_2 is released by the stomata which are on the underside of the leaf of the plant. Thus when the plant is inverted, the CO_2 is not trapped beneath the plant's leaf, and is free to move. The Blu-Tac / Plasticene / paperclip is used to weigh down the *E*lodea specimen in the boiling tube.. This makes sure that the entire plant is submerged in the $Na^+HCO_3^-$ solution and therefore the entire plant is exposed to the CO_2 released by the $Na^+HCO_3^-$. *H*owever, this weight covers as few leaves as possible, thus reducing the chance that the *CO2* production / release will be interfered with. Also, the weight must not cover the very tip of specimen, the meristem; this tip of the plant is where the plant is growing the most, and thus photosynthesising the most. The end of the plant should be cut at an angle, in order to release CO_2 most effectively. The thermometer monitors the temperature of the water bath, thus checking whether or not there is a temperature increase or decrease, resulting in the change in the rate of p/s in the *E*lodea specimen. A change in the temperature would prevent the investigation from being a fair test. *H*ence, maintaining a constant temperature and CO_2 level maintains a fair test, with only one variable changing - the LI. *C*ounting the number of bubbles produced by the *E*lodea would be a fairly reliable way of measuring the CO_2 produced. *O*bviously affixing a gas syringe to the top of the boiling tube would be far more reliable, but I doubt that there would be a sufficient volume of CO_2 in a short time (max *3* mins) produced to make a considerable difference when reading the volume of gas produced by the *E*lodea specimen. By counting the number of bubbles, we are assured of a sufficiently large reading. The *E*lodea must be left for a sufficient amount of time for it to adjust to the new LI; I believe that five minutes should be ample enough - this will be consolidated by the preliminary results. Repeat readings must be taken to establish that there are no anomalous results - two extra readings should be sufficient (again the number will be determined by the preliminary results). The repeat readings will be taken after the original

reading has been taken in the same manner as the original result. Anomalous results (if there are any) should be ascertained by the repeat readings.

In this experiment, there is little opportunity for accidents; however, the lamp will get somewhat hot during the experiment, and one must be careful not to burn oneself during the experiment. Also, utmost care must be taken, as ever, when working with glass apparatus, due to the risk of the shattering of the glass leading to injury.

The method will be as follows:

Set up apparatus as in diagram

Leave the cut *E*lodea for five minutes to adjust to the altered LI

Record the numbers of bubbles of CO_2 produced in one minute

preliminary results

Using this setup and apparatus, I encountered the following problems:

9cm of *E*lodea did not fit into the boiling tube. Hence, the length of the specimen was reduced to 7cm, which did fit into the boiling tube. Five minutes was left for the *E*lodea to adjust to the LI. Then the number of bubbles of CO_2 produced in a minute by the *E*lodea was measured. Two repeat readings were taken, and the three results averaged out. The averages are:

Distance / cm LI (1000 up>*2*) Bubbles / min Temp of water bath / °c

5 40 immeasurable *2*6

10 10 immeasurable *2*5

15 4.444 (to 3dp) 46 *22*

…

35 0.816 (to 3dp) 16 22

40 0.625 9 22

45 0.494 (to 3 dp) ½ 22

When the distances were less than 15cm, there were so many bubbles produced that it was impossible to count them, and also, the temperature was raised, thus preventing the

experiment from being a fair test. However, at 15cm, it was possible to count the number of bubbles produced, and from this point onwards, the temperature remained constant. Ergo, I will take readings from 15cm onwards. Yet, when the distances were more than 40cm, there was only a maximum of one bubble produced every other minute (ie. ½ a bubble per minute). As this is less than 1, I have chosen to ignore readings of d 40cm.

The 5 minutes adjustment time appears to have worked, as the readings are constant. Hence this time will be kept the same in the final experiment.

Consequently, I will change the following:

I will take measurements between 15cm and up to 40cm inclusive only

I will use 7cm of Elodea

method

The apparatus was set up as in the planned diagram. The lamp was set fifteen centimetres from the Elodea specimen, and the specimen was allowed to adjust to the new light intensity for five minutes. Then amount of bubbles produced in one minute were counted. This was repeated twice, and the distance increased by five centimetres. The plant was left to adjust, readings taken and the distance changed up to 30 cm, this being the only number of measurements time allowed.

results

The followings results were obtained

Distance / cm LI (1000 up>2) Bubbles / min Temp of water bath / °c Observations

15 56 22 22 Bubbles

15 4.444 63 22 22 produced

15 57 22 22 erratically

20 49 22 22 Steady

20 2.5 49 22 22 stream of

20 51 22 22 bubbles

25 33 22 22

25 1.6 37 22 22 None

25 40 22 22

30 22 22 22

30 1.111 24 22 22 None

30 21 22 22

Average - plot points

Graph 1		Graph 2
Distance / cm	LI (1000÷D2)	Bubbles / min
15	4.444	58.67
20	2.5	50.33
25	1.6	36.67
30	1.111	22.33

These *results* h*a*ve been *plott*ed on *graph paper*

analysis / conc*lusion*

From *the graphs* we c*an see that as light intensity increases, the production* of CO2 *increases* (*and thus the rate* of *photosynthesis*) un*to the* LSP (L*ight* S*aturation* Po*int*). The *graphs suggest that the* LSP fo*r* E*lodea is* when *the* LI 4.5. Thus *the distance at* which *the* E*lodea should reach its* LSP *is*:

1000

LI = ---

d^2

d = 1000

□ (1000 5) 14.90711985 15

Thus, one co*uld predict that at distances less than* ~15 cm (*and therefore light intensities greater than* ~4.5) *the* numbe*r* of bubb*les* of CO_2 *p*roduced by *an* E*lodea specimen* wou*ld* be *approximately* uni*form*.

When *it* comes *to the slightly anomalous result* shown on *the* LI *vs. Bpm graph*, *there is a simple* way *to explain this*; E*lodea is a living organism*, *and* no *living organism follows a*

regimented pattern. Thus we can say that this anomaly is due to the specimen being not entirely infallible.

As I predicted, the rate of photosynthesis increased constantly unto the LSP because all limiting factors, other than light, were kept consistently the same. Thus these results support my prediction.

evaluation

I feel that this experiment has been successful in fulfilling the objective. The planned procedure worked fairly well, needing only a few minor adjustments to obtain good results. The evidence obtained supports photosynthetic theory and my prediction; it appears to be sound.

As mentioned before, the only (slightly) anomalous result is simple to explain; Elodea, being a living organism will not produce uniform results - thus the anomaly, it can be said, is due to the fallibility of the specimen.

No problems were encountered; the only circumstance which would have been a difficulty would have been controlling the temperature. However, this was eliminated by putting the boiling tube into a water bath which absorbed the majority of the heat energy from the lamp, and by keeping the specimen far away enough from the lamp for there to be no significant change in temperature.

This experiment is rather crude, and the method of measuring the rate of photosynthesis especially; counting the number of bubble of CO_2 produced in a minute is not very accurate - measuring a volume would be far more precise, but the time for a reasonable amount of CO_2 to be produced would be rather long, I feel; this would be inappropriate I believe, where time is limited.

Further work could be carried out, investigating the effects of the quality of light on the rate of photosynthesis; different coloured light for example could be used. This could be of commercial benefit, as finding out the effect of the colour of light on the rate of photosynthesis could aid plant growers to find out which type(s) of light make(s) plants grow quickest.