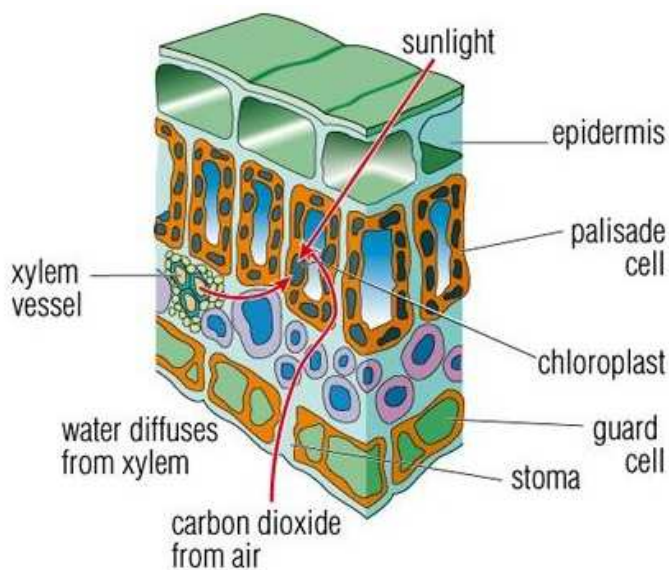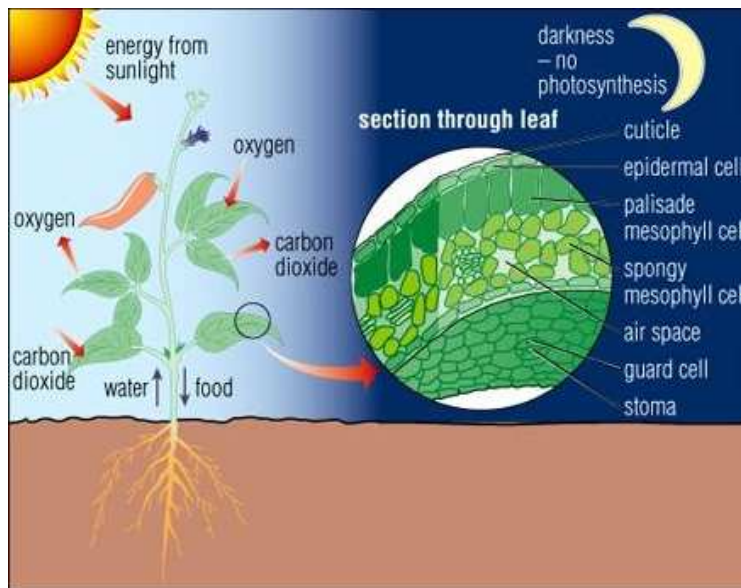What is **Photosynthesis?**

Process by which green plants trap light energy from the Sun. This energy is used to drive a series of chemical reactions, which lead to the formation of carbohydrates. The carbohydrates occur in the form of simple sugar, or glucos e, which provides the basic food for both plants and animals. For photosynthesis to occur, the plant must possess chlorophyll and must have a supply of carbon dioxide and water. Photosynthesis takes place inside chloroplasts, which are found mainly in the leaf cells of plant.

The by - product of photosynthesis, oxygen, is of great importance to all living organisms, and virtually all atmospheric oxygen has originated by photosynthesis.

Chloroplasts contain the enzymes and chlorophyll necessary for photosynthesis, and the leaf structure of plants is specially adapted to this purpose.

The equation of photosynthesis is $CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2$

The Structure of a Leaf (left)

<u>Aim</u>

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

<u>Background</u>

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 fe ed.

Light

$$6CO_2 \; + \; 6H_2O \; \rightarrow \; C_6H_{12}O_6 \; + \; 6O_2$$
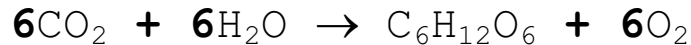
Raw materials   Products

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 pro duced. 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 da ylight 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 s ame 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, t he rate of p/s increases, until the plant is photosynthesising as fast as it can - the LSP – **L**ight **S**aturation **P**oint. When the LSP is reached, plants cannot photosynthesise any faster, even when the light gets brighter. From this point on, according to Blac kman'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 CSP - CO_2 **S**aturation **P**oint. If both CO_2 and light supply are increased together, the rate of p/s will level out. Henceforth it is limited, according to Blackman's Law, by the factor in least supply, either H_2O or temperature. however there is a phys ical 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 CSP is quickly reached. At a higher temperature, the rate of p/s increased further and reaches the LSP / CSP 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 *Elodea*, one must keep both the amount of CO_2 <u>and the temperature</u> 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 descri bed as

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

$$LI = \frac{1}{D^2}$$ by 1000 makes the LI a more 'workable' number. $LI = \frac{1}{D^2}$

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 variabl es 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
- *Elodea* Candensis specimen

- Electric 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 *Elodea* 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 *Elodea* 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 *Elodea* 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 $Na^+HCO_3^-$. However, 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 *Elodea* specimen. A change in the temperature would prevent the investigation from being a fair test. Hence, maintaining a constant temperature and CO_2 level maintains a fair test, with only one variable changing - the LI. Counting the number of bubbles produced by the *Elodea* would be a fairly reliable way of measuring the CO_2 produced. Obviously 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 *Elodea* specimen. By counting the number of bubbles, we are assured of a sufficiently large reading. The *Elodea* 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 *Elodea* 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 *Elodea* did not fit into the boiling tube. Hence, the length of the specimen was reduced to 7cm, which <u>did</u> fit into the boiling tube. Five minutes was left for the *Elodea* to adjust to the LI. Then the number of bubbles of CO_2 produced in a minute by the *Elodea* was measured. Two repeat readings were taken, and the three results averaged out. The averages are:

Distance / cm	LI ($1000÷D^2$)	Bubbles / min	Temp of water bath / °c
5	40	immeasurable	26
10	10	immeasurable	25
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 onwa rds. 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 [3]40cm.

The 5 minutes adjustment time appears to h ave 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 appa ratus 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÷D²)	Bubbles / min	Temp of water bath / °c		Observations
15	ü 56		22	22	Bubbles
15	ý 4.444	63	22	22	produced
15	þ 57		22	22	erratically
20	ü 49		22	22	Steady
20	ý 2.5	49	22	22	stream of
20	þ 51		22	22	bubbles
25	ü 33		22	22	
25	ý 1.6	37	22	22	None
25	þ 40		22	22	
30	ü 22		22	22	
30	ý 1.111	24	22	22	None
30	þ 21		22	22	

Average - plot points

These results have been plotted on graph paper

Analysis / conclusion

From the graphs we can see that as light intensity increases, the production of CO2 increases (and thus the rate of photosynthesis) unto the LSP (Light Saturation Point). The graphs suggest that the LSP for Elodea is when the LI ≈ 4.5. Thus the distance at which the Elodea should reach its LSP is:

$$LI = \frac{1000}{d^2}$$

$$\therefore \quad d = \sqrt{1000 \div LI}$$

$$\therefore \quad \sqrt{(1000 \div 4.5)} = 14.90711985 \approx 15$$

Thus, one could predict that at distances less than ~15 cm (and therefore light intensities greater than ~4.5) the number of bubbles of CO_2 produced by an Elodea specimen would be approximately uniform.

When it comes to the slightly anomalous result shown on the *LI vs. Bpm* graph, there is a simple way to explain this; Elodea 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.

<u>Evaluation</u>

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 CO2 produced in a minute is not very accurate - measuring a volume would be far more precise, but the time for a reasonable amount of CO2 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.