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Investigating the effect of Light Intensity on Elodea

Aim:

The aim of my experiment is to determine whether or not the intensity of light would affect the rate of photosynthesis in a plant. To do this I will place different pieces of Elodea (pondweed) into a beaker and expose it to varied light intensities, and observe the amount of oxygen given off by the plant.

Introduction:

Photosynthesis is the process of converting light energy into chemical energy and storing it in the bonds of sugar.
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. It is the chemical process, which takes place in every green plant to produce food in the form of glucose. Plants use the suns energy to join together water and carbon molecules to make the glucose, which is sent around the plant to provide food. Cells in the root or stem can use the glucose to make energy, if the plant does not need to use all the glucose immediately then it is stored as starch.

It is possible to measure the rate of photosynthesis by counting how many bubbles or the volume of oxygen produced. In this experiment I will collect data to see if it supports my prediction.

The following chemical equation summarises photosynthesis:

Carbon dioxide + water ⟶ glucose + oxygen

$$CO_2 + H_2O \longrightarrow C_6H_{12}O_6 + O_2$$

From this equation we can see that the photosynthesis reaction requires light. Light is a form of energy, and when it falls on the chloroplasts in the leaf, it is trapped by chlorophyll, which then makes the energy available for chemical reactions in the plant. As the amount of light (energy) falling on the plant increases, the more energy chlorophyll can trap, so more energy is available for chemical reactions, so more photosynthesis can take place in a given time.

If the plant had a plentiful supply of carbon dioxide and water, the only limiting factor would be light. The rate of photosynthesis would increase with an increase in light intensity up to the point that light is no longer the limiting factor.
Light provides energy so that carbon dioxide and water can bond to make glucose. When the glucose is used (the bonds broken), a large amount of energy is released.

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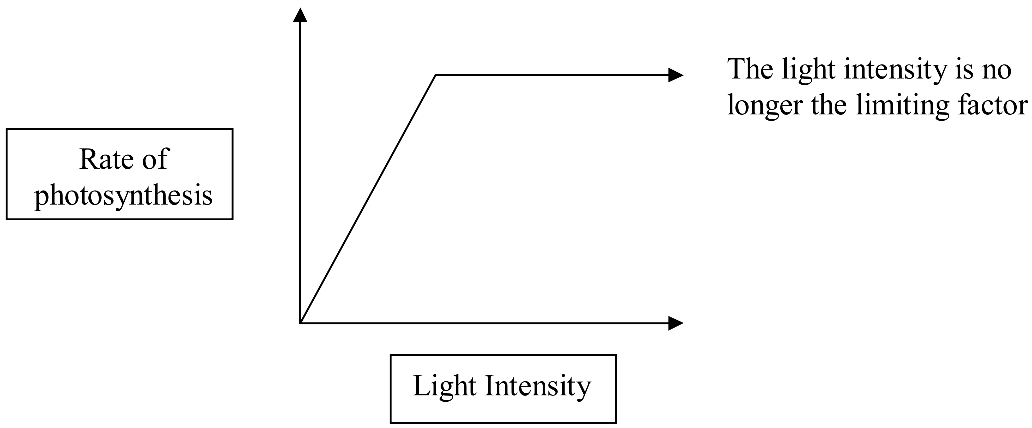

If the distance of a lamp from the plant is known, light intensity can be calculated:

Light intensity = $1/d^2$ (d = distance)

Prediction:

I predict that as light intensity increases, the rate of photosynthesis will increase at a proportional rate until a certain level is reached where an increase in light intensity will have no further effect on the rate of photosynthesis, as there will be another limiting factor.
I predict that the graphs plotted will be non-linear, they will be curves of best fit. Light intensity is inversely proportional to the distance squared because the light energy spreads out as it travels further from its source. As light energy is released from a point, it is dispersed equally along the circumference. As the distance increases, the same amount of light has to be dispersed along a larger area. I intend to do preliminary work so that I have an idea of how to carry out my final experiment. Preliminary work can give an idea of the results, and whether there is any correlation and any point to continue studying. Preliminary work lets us test our method and whether there are any other factors that need to be taken into account.
Preliminary experiments allow us to decide on a suitable range (distance) to investigate light intensity. To alter the light intensity I placed the lamp at various distances from the plant.

Simplest method to use:

I have decided to use the bubble counting method, as it is simple. It would be much more difficult to measure the volume of oxygen, to get data. Counting bubbles gives numerical data, volume of oxygen would perhaps be more accurate, but very hard to measure accurately. With the equipment available and expertise, it would be easiest to use the bubble counting method.

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<u>Preliminary work:</u>

Method used:
Cut pondweed at both ends so that the plant is fresher. The length of the plant should be the same every time (20cm). The longer the plant, the closer to its natural form it is, the more accurate and reliable our results are. The Elodea we received to work with were of about 30cm in length, cutting it down too much would not be a true representative of the plant in its natural state. Fill a beaker with water (500cm^3) of water and add a spatula of sodium hydrogen carbonate. Place a funnel and an upturned test tube full of water over the Elodea (as shown below):

Measure a distance with a 1m rule e.g. 50cm from the plant and place the lamp there. Then time with a stop clock how many bubbles are produced within a certain length of time at that distance.
I took several results for my preliminary experiment and worked out an average. These are the preliminary results obtained:

Distance from Lamp (cm)	No. of bubbles (per min) experiment 1	No. of bubbles (per min) experiment 2	No. of bubbles (per min) experiment 3	Average no. of bubbles (per min)
10	46	48	47	47
20	44	42	43	43
30	40	34	37	37
40	33	34	32	33
50	27	25	26	26
60	17	18	16	17

From this we can see that there is a definite correlation. As the distance from the plant increases the number of bubbles decreases. For my final experiment I intend to record results from the following distances: 50, 45, 40, 35, 30, 25, 20, 15, 10, 5. I do not intend to record no. of bubbles produced from a distance of 0cm, because the lamp would heat up the experiment too much, making the test unfair. I will not record results at any distance above 50cm, because the light source will be too far away to show any significant result.
<u>Note</u>: it is best to count the number of bubbles produced, if observing from the opposite side of where the light is coming from. It makes it easier to count the bubbles, as they are more visible.

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Variables:

Control variables/ fair testing:

- Wash pondweed to remove living micro-organisms that will respire and produce bubbles, making the experiment unfair, as the bubbles that they produce will be counted as bubbles produced by the photosynthesising plant.
- Water is important to the photosynthesis reaction, as when there isn't enough the plant's stomata close to prevent further water loss, this also cuts down the amount of carbon dioxide able to diffuse through. In this experiment water will not be a limiting factor as the plant is fully submerged in water. Keep the amount of water in the beaker the same for all experiments. This means that the concentration of carbon dioxide would be the same for all experiments meaning that carbon dioxide amount is not a variable and does not affect the results by being a limiting factor. (Use enough water to submerge the Elodea- about $500cm^3$).
- 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 denature. Try to keep the water temperature constant – room temperature. This may be difficult because as the lamp is positioned closer to the plant it emits heat, heating up the water in the beaker. At a higher temperature there is more energy which the plant can use to photosynthesis (react carbon dioxide and water). Temperature increases the speed of the reaction, the plant respires more, producing more bubbles. This would mean that the experiment is inaccurate as it is not testing the sole effect of light intensity, but combining it with the effect of temperature.
- Make sure that there is only one light source being used on the plant at any one time i.e. experiment in a dark room so that natural light doesn't interfere with the experiment. Natural light- from outside would have a different intensity at different times of day. Keep the lighting in the room the same throughout each experiment by shutting blinds, turn of lights.
- Time the experiment. Count the number of bubbles produced by the plant within a certain amount of time, alternatively you could time how long it takes for the plant to produce a certain amount of bubbles (e.g. 20). This method would perhaps take longer to do, if the lamp were to be positioned far away from the plant the rate of photosynthesis would be much slower. It would take a considerable amount of time for 20 bubbles to produced at a length of 60cm, but only a matter of seconds for this amount to be produced at a length of 5cm. The timed result for 5cm would perhaps be inaccurate as it is hard to get an accurate time when bubbles are being produced at high speed (found out in preliminary exp.).
- Keep the length of pondweed the same. The size of the plant and how many leaves are on it makes a difference to the number of bubbles produced (found out in preliminary exp.). The larger the number of leaves the more sunlight that they can trap and therefore the faster the rate of photosynthesis. The length needs to be the same in each experiment so that light intensity is the only variable. Length of Elodea used in preliminary exp. – 20cm.
- Cut the ends of the pondweed so that the opening is fresh, not dying away (as done with flowers). Cut the ends at an angle so the bubbles come out faster because the opening of the stem is bigger.

- Keep the carbon dioxide concentration optimal, as carbon dioxide is needed in the photosynthesis reaction. Too much carbon dioxide means that the plant will die, too little means the plant can't photosynthesise and will also die. To keep the carbon dioxide level optimal, a ¼ spatula of sodium hydrogen carbonate (this gives the plant a dissolved supply of carbon dioxide)
- Chlorophyll is the green pigment in the chloroplasts. Chlorophyll is what allows photosynthesis to take place. Without it, the plant would not be able to photosynthesise.

Input Variable:

- Light intensity must be the only variable in this experiment as it is the point of the investigation. All other factors are kept constant so that the results obtained are as accurate as possible. Light intensity is to be varied by increasing and decreasing the distance from the light source to the plant.

Output Variable:

- Rate of photosynthesis is to be measured by finding the volume of oxygen produced in a minute at varied light intensities.

Apparatus:

- 1 measuring cylinder – 500cm3 (a measuring cylinder is used, because we found (in the preliminary exp.) that it is easier to see and count the bubbles in this shape cylinder).
- 3 pieces of Elodea pondweed – 20cm in length.
- 1 Scalpel to cut the ends of the Elodea
- 1 Stop clock to time the experiment
- 1 white tile
- 1 Spatula
- 3x ¼ Spatula of sodium hydrogen carbonate
- 1m ruler

Safety:

- Keep the lamp and electricity plug + socket away from any water. Make sure hands are dry before going near any electricity source.
- Cut the ends of the Elodea using a scalpel on the tile facing away from you.

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Method:

1. Fill the measuring cylinder up to the 500cm3 mark, with water
2. Add ¼ spatula of sodium hydrogen carbonate to give a supply of carbon dioxide to the Elodea.
3. Get 3 pieces of Elodea. Cut them at each end at a slight angle so that each length of Elodea is the same and measures to about 20cm. The Elodea should be cut at an angle so that bubbles come out faster because the opening of the stem is bigger. The angle should be the same, so that the test is fair, a bigger opening would let out more bubbles than a smaller opening.
4. This process should be done under water so that air bubbles aren't trapped in the ends of the Elodea. It should be done carefully with a scalpel on tile, cutting away from your body.
5. Place one length of Elodea into the measuring cylinder.
6. Close the blinds and turn off all the lights.
7. Place the lamp at a measured distance from the Elodea (using a 1m ruler). E.g. start the experiment with a distance of 50cm from the Elodea. 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.
8. Turn the lamp on, and give the Elodea about 2min to adjust to this light intensity. Then time with a stop watch and count how many bubbles are produced in 1min at that light intensity. Repeat at the same light intensity for a second and third time and record results.
9. Repeat the experiment at the following distances: 50, 45, 40, 35, 30, 25, 20, 15, 10, 5cm from the plant.
10. Repeat the whole experiment using 2 more pieces of Elodea.
11. Record all results into a table, and graphs. The graphs are useful to see patterns in data.

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Results: Table to show how many bubbles produced by the plant within a minute at several distances (light intensities)

Distance of lamp from plant	Elodea no. 1		Elodea no. 2		Elodea no. 3	
	1	2	1	2	1	2
5cm	60	64	67	65	63	64
10cm	49	51	50	53	49	49
15cm	38	39	40	39	39	38
20cm	35	36	34	33	34	35
25cm	29	30	30	28	30	29
30cm	25	25	26	24	27	26
35cm	23	24	23	22	23	23
40cm	19	21	19	20	20	20
45cm	17	18	16	17	19	16
50cm	11	13	10	12	15	14

Average no. of bubbles per minute (60s).
5cm: 64
10cm: 50
15cm: 39
20cm: 35
25cm: 29
30cm: 26
35cm: 23
40cm: 20
45cm: 17
50cm: 13

Analysis:

General pattern:
From the results I have gathered, it is obvious that the rate of photosynthesis does increase with an increase in light intensity. Light intensity was varied by altering the distance of the lamp from the plant. As the lamp is moved closer to the plant, the rate of photosynthesis increases. A greater light intensity means that more light energy is available so that the plant can use this energy to photosynthesise.
Looking at graph 1, it is obvious that when the distance of the lamp from the Elodea is at its shortest length (5cm), the average number of bubbles is 64 bubbles per min with a light intensity of 0.04 lux. This means that the rate of photosynthesis was at its highest. However, when the distance of the lamp from the Elodea is 50cm, the average number of bubbles is only 13 with a light intensity of 0.0004 lux. This means that the rate of photosynthesis was at its slowest in this experiment. There is a considerable range in the number of bubbles produced, and since the only variable was light intensity, it is the only explanation.
The graphs produced were curves of best fit. This means that the rate of photosynthesis increases exponentially. From the results obtained, it is possible to see that as the distance of the lamp from the plant decreases the curve of best fit becomes steeper, i.e. the number of bubbles produced increases at a greater rate. There are points on the graph where the decrease in the number of bubbles is proportional to the increase in distance (i.e. a straight line- linear). The points were at 25cm, 30cm, 35cm, 40cm, 45cm, and 50cm.

Conclusion:

Photosynthesis is a reaction that requires light energy to work. In this experiment, a lamp is the source of light energy for the Elodea. As the lamp is moved closer to the plant, the light intensity increases- i.e. more of the light rays fall onto the plant's leaves. When light falls on the leaves, the energy is absorbed by chlorophyll, which is inside cells called chloroplasts. Chlorophyll is pigmented green.

Light is an input of photosynthesis, the light energy is used to form bonds between carbon dioxide and water, producing oxygen. Oxygen bubbles are the product of photosynthesis. As light intensity increases, so does the rate of photosynthesis and more bubbles are given off as a product of the reaction. The collision theory can be used to explain why the reaction is speeded up when more energy is available. All atoms have kinetic energy, these atoms move, colliding with each other. When they collide the activation energy must be enough to let the particles react. If more energy is available, the kinetic energy is greater, so the atoms move at a greater speed. So when the particles to collide, they collide with each other with more force, therefore the activation energy is larger, making the particles more likely to react with each other. In this case, the particles are carbon dioxide and water reacting with each other to form glucose and oxygen. The more light that is available means that there is more energy available, and therefore more bonds are broken and made which results in a faster rate of photosynthesis.
On the first graph there was one anomalous result: at the distance of 20cm. This is obvious because it did not fit into the curve of best fit.
On the second graph there were several anomalous results: at the distances of 10cm, 30cm, and 35cm. The anomalous results were circled.

In conclusion, the results obtained support my prediction to the extent that light intensity does have an effect on the rate of photosynthesis. The effect is that, if light intensity is increased, the rate of photosynthesis will also increase. This is because a greater light intensity involves a greater level of light energy. Light energy is in the form of a photon. The energy from a photon is absorbed by the green pigment of chlorophyll and used to transfer electrons from one chlorophyll pigment to the next. This energy is stored as chemical potential energy in the covalent bonds of sugar molecules.
Both graphs were non-linear, showing that the results were exponential, not proportional, also supporting my prediction.

<u>Evaluation</u>

<u>Quality, accuracy and suitability of methods used:</u>
Overall, I am pleased with the results obtained from the experiment, as the predicted trend was evident. The method used was suitable in finding relationships between distances and support my prediction, however not accurate enough to produce results that can prove my prediction, or support a firm conclusion.
The data produced gave a few anomalous results on graph 1, at distance 20cm and on graph 2 at distance cm. However the general pattern was that the shorter the distance between the plant and light, the more bubbles were produced.
Measuring the volume of oxygen produced would have been more accurate, as the size of the bubbles that were produced varied considerably. However, due to the lack of equipment and a greater possibility of operator error in measuring the actual volume, I had to confine the experiment to simply counting bubbles.

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What could have made experiment unfair/ produced anomalous results:
An anomalous result is when the technique was slightly varied in one experiment. This could be due to:

Design errors:

- Light from other experiments in the room or from windows could have been shining on my experiment increasing the amount of light given, while not recorded. Attempts were made to decrease the amount of light in the room by closing blinds and moving experiments away, however, there were still large amounts of light in the room. In my opinion, this factor would only have effected my results marginally. To overcome this factor, a sheet of cardboard could be placed surrounding the Elodea, so that only light from the lamp can reach it. This also insulates the plant, maintaining a constant temperature.
- The size of bubbles given off by the plant varied greatly. This made the experiment also unfair as large and small bubbles were all worth one tally. In this type of experiment, measuring the volume of oxygen produced would have been most suitable, however more difficult.
- Carbon dioxide concentration could have affected the rate of photosynthesis. If there was too little sodium hydrogen carbonate added to the water, this would have limited the rate of photosynthesis. However, I do not think that the results of my experiment show this to be true, as there is no sudden levelling off. I carried out my experiment over a short period of time, not giving the plant enough time to use up the carbon dioxide (sodium hydrogen carbonate) added to the water. To try to overcome this factor, a constant amount ($^3/_4$ spatula) of sodium hydrogen carbonate was added to every experiment.
- The leaves on the Elodea were curved so that oxygen bubbles could have been trapped under them. This meant that no all of the oxygen produced was accounted for. To overcome this factor, the cylinder containing the Elodea should have been slowly shaken to release the oxygen bubbles produced.
- A plant also respires (usually at night when there is no light to photosynthesise). In respiration a plant uses oxygen, so the oxygen produced, some of it could have been recycled and used to respire, making the oxygen bubbles released smaller. In my opinion, this was not a major factor in the experiment, as enough light was available (however at lower light intensities- this could have been a problem). To overcome this problem, the experiment would have to be repeated in the dark, to find out the rate of respiration, taking it into account.
- Chloroplast concentration vary throughout the leaf. Where there is a larger concentration of chloroplasts, there is a larger concentration of chlorophyll, meaning that there would be more photosynthesis occurring in that part of the plant. This means that more oxygen would have been produced on that part of the plant. So the amount of oxygen produced have varied in different parts on the plant, and also on different plants. Plants of similar shades of green should have been chosen to experiment on; on the contrary plants of varying shades could have been chosen to experiment on, and then an average taken. This would give an average of most Elodea plants.

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Instrument errors:

- The lamp heated up, emitting heat energy. When the lamp was moved nearer to the plant, the heat could have been emitted to heat up the pond water. Heat energy increases the rate of photosynthesis, and would also therefore make the experiment unfair as light would not have been the only factor affecting the experiment. To overcome this problem, a sheet of clear plastic or glass could be placed in between the lamp and the Elodea. This would not interfere with light travelling to the plant, but would prevent heat from reaching the plant.

Operator errors:

- The angle at which the tips of the Elodea plant were cut could have affected how fast the bubbles come out and the size of the bubbles. The larger the surface area, the larger the bubbles, and the faster they would have come out. The plant was cut to the same length, but it was difficult to ensure that the tips were all cut at the same angle.
- A minor error could have been the accuracy of the distance measured between the lamp and plant. Ideally, the distance should have been measured from the filament of the lamp, to the centre of the plant.
- Another inaccuracy could have been the time keeping. The problem was when to begin the experiment (when to start timing). I started my clock once 1 bubble had been produced. This ensured that the reaction had started and was at a steady rate.
- Bubbles were difficult to count, as at short distances the speed at which bubbles were produced was very fast. Light shone off the cylinder, making it hard to observe the bubbles. To overcome this problem, the method of measuring the volume of oxygen should have been carried out.

Limitations: whether light was the limiting factor in the experiment.
My prediction of light intensity no longer being a limiting factor could not be investigated, as a distance of zero cm could not be investigated. However, different light bulbs of various intensity's could have been used to investigate this prediction. A bulb of greater intensity could have been used to calculate where the graph levels of due to other limiting factors.

Reliability of Evidence:
The evidence cannot be taken to support a firm conclusion as the test was not very reliable due to equipment and method used. In my opinion, the experiment was not repeated enough times as the results seemed to be quite different from each other, and I was unsure of which results were anomalous. In my opinion, if I had obtained a mode result then I would be more able to support a conclusion.
In my prediction I wrote that as light intensity increases, so would the rate of photosynthesis at a proportional rate. My results can support this prediction, although not prove the fact that the rate increases proportionally because my results are not reliable enough. My results cannot support the prediction that the rate of reaction will level off when light is no longer a limiting factor, because I did not increase the light intensity enough for it to no longer be a limiting factor.

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My results did form a curve, which supports the notion that light intensity is inversely proportional to the distance squared because the light energy spreads out as it travels further from its source.

To further investigate:

- A wider range of light intensities- to observe when light is no longer the limiting factor. This would have to be done by using brighter light bulbs.
- How different coloured lights affect the rate of photosynthesis.
- Experiment on a wider range of plants, observing patterns and trends.
- Investigate how carbon dioxide affects the rate of photosynthesis.
- Investigate how the availability of water affects the rate of photosynthesis.
- Investigate how temperature affects the rate of photosynthesis.

References:

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http://www.essaybank.co.uk
Letts science revision guide