Use and Production of Carbon Dioxide and Oxygen by Plants and Animals During Photosynthesis and Respiration

1601 ENV: Biological Systems

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Abstract

Respiration occurs in plant and animal cells, uses oxygen and results in the production of energy, water and carbon dioxide from the break down of sugars. Photosynthesis occurs in some plant cells and uses light energy to synthesise sugars from carbon dioxide and water, resulting in oxygen production. Three experiments were carried out to observe gas exchange by plants and animals during respiration and photosynthesis. The first analysed oxygen consumption during respiration using a respirometer to measure the effect on the volume of air in a closed system due to oxygen production by respiring mung beans. The change in air volume was indicated by the movement of a drop of dye in a capillary tube. The net decrease in air volume caused the dye to move 92mm. The second measured the effect of light on oxygen production in photosynthesising leaf sections by removing the air from them and sinking them in three beakers of sodium bicarbonate solution, placed in different light conditions. The photosynthesising leaf sections were observed as they begun to float due to oxygen production. After 12 minutes, 100 percent of leaf sections in the beaker 150 mm from the light, 70 percent in the beaker 200 mm from the light, and none in the beaker in the dark, were floating. This confirmed that light intensity noticeably increased rates of photosynthesis. The third involved noting the effect of various respiring and photosynthesising marine organisms on carbon dioxide concentrations in water, as indicated by Bromothymol Blue. It was concluded that organisms with higher energy requirements respired more and therefore produced more carbon dioxide.

1.0 Introduction

Respiration is the cellular process by which plants and animals use organic compounds to produce energy that can be used to drive various processes within the organisms (Campbell et al. 2006:160). It involves a series of metabolic reactions that harvest the biochemical energy in the bonds of these organic compounds and synthesize adenosine triphosphate (ATP), which is used to store this harvested energy (Campbell et al. 2006:162-3). These reactions are catabolic redox reactions, which use oxygen, involve the transfer of electrons and produce carbon dioxide and water as waste products (Campbell et al. 2006:168). Respiration in plant and animal cells involves three stages, which are; glycolysis, the Krebs cycle and the electron transport chain (Campbell et al. 2006:164). Glycolysis is the breaking of bonds in the organic compound to form smaller organic molecules (such as pyruvate), to produce energy by substrate-level phosphorylation (stored as ATP) and electrons, which are harvested to form reduced nicotinamide adenine dinucleotide (NADH) (Campbell et al. 2006:165-7). Between glycolysis and the Krebs cycle, a transition step exists, which involves the oxidative decarboxylation of the pyruvate molecules (CH_3COCO_2H) to form carbon dioxide and acetyl-CoA, which is then implemented into the Krebs cycle (Campbell et al. 2006:168). The Krebs cycle involves a series of oxidation-reduction reactions that result in the production of energy stored in 28 ATP molecules and 16 pairs of electrons, harvested and stored in NADH and reduced flavin adenine dinucleotide ($FADH_2$) (Campbell et al. 2006:168-170). Carbon dioxide and water are also produced as waste products during the Krebs cycle (Campbell et al. 2006:168-170). The electron transport chain involves the transfer of the high-energy electrons stored in NADH and FADH2 molecules down a chain of proteins in the inner mitochondrial membrane to create a proton gradient across the membrane (Campbell et al. 2006:170-4). This energy is used to power ATP synthesis by oxidative phosphorylation (Campbell et al. 2006:171). The overall equation for respiration (where glucose is used as an example of an organic compound) is:

$C_6H_{12}O_6 + 6\ O_2 \rightarrow 6\ CO_2 + 6\ H_2O$ + Energy (ATP + heat) (Campbell et al. 2006:161)

Photosynthesis is the cellular process by which plants use carbon dioxide and water to form organic compounds, such as sugars, where oxygen is released as a by-product (Campbell et al. 2006:181). During this process, visible light energy is converted to chemical energy and is stored in the bonds of these organic compounds (Campbell et al. 2006:182). It is a process that occurs in the chloroplasts in the cells of the green parts of plants (Campbell et al. 2006:183). Photosynthesis involves two stages, the light reactions and the dark reactions (Campbell et al. 2006:184-5). The light reactions occur in the thylakoid membranes of chloroplasts and use the energy from light to store harvested electrons as reduced nicotinamide adenine dinucleotide phosphate (NADPH) and to produce energy stored as ATP (Campbell et al. 2006:190-1). Oxygen is also produced during the light reactions by the splitting of water molecules (Campbell et al. 2006:184). The dark reactions fix carbon dioxide into organic compounds and, although they are not directly dependant on light, they do require the products of the light reactions (Campbell et al. 2006:193-4). The electrons stored in the NADPH and the chemical energy stored in the ATP during the light reactions are used for carbon fixation in the dark reactions. The series of reactions that are involved in this process is called the Calvin cycle and result in the synthesis of organic compounds (Campbell et al. 2006:194-5). The Calvin cycle consists of enzymes and intermediates found in the stroma within the chloroplasts (Campbell et al. 2006:193). The overall equation for photosynthesis is:

$6\ CO_2 + 6\ H_2O$ + Light energy $\rightarrow C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$ (Campbell et al. 2006:183)

When light is limited, the plant reserves energy by stoping photosynthesis and using energy to respire (Campbell et al. 2006:198).

In order to gain an understanding of production and consumption of gasses by organisms during respiration and photosynthesis, three experiments were conducted. The first was designed to analyse the effect of respiration on the volume of air, the second involved observing the effect of light intensity on the production of oxygen during photosynthesis, and the third involved noting variations in gas production and consumption by various marine organisms in differing light conditions.

2.0 Methods

2.1 Oxygen Consumption in Respiration

In order to measure the oxygen consumption of germinating mung beans, two respirometers were set up, each of which consisted of a vertical glass cylinder, held upright by a stand and clamp, and a smaller, horizontal measuring capillary tube, inserted in a plug on top of the vertical cylinder. One apparatus was set up to measure the consumption of oxygen in respiration by the mung beans (respiration chamber) and one to act as a control (compensation chamber) to account for potential variations in the results caused by outside factors such as temperature.

In the respiration chamber, germinating mung beans were first inserted, then 12 potassium hydroxide pellets on a bed of cotton wool, to protect the mung beans from contact with them. The potassium hydroxide pellets absorbed carbon dioxide in the respirometer (Portugual 2008:3495) and the mung beans were not green and therefore weren't photosynthesizing (Walker & Crofts 1970:398). This ensured that observed changes in air volume within the respirometer were a result of oxygen consumption during respiration. In the compensation chamber, pebbles were used in

place of the mung beans, as they are not living organisms and don't respire (Campbell et al. 2006:160). The purpose the control was to account for any changes in air pressure within the respirometer that were not a direct result of respiration.

After setting up the apparatus, the respirometer was left to reach equilibrium for five minutes then was sealed by inserting a small drop of Bromothymol Blue die at the opening using an eyedropper. The respirometer was left for a further three minutes then movement of the die (in millimetres) in both respirometers was recorded simultaneously at one-minute intervals for five minutes.

2.2 Effect of Light on Oxygen Production in Photosynthesis

In order to measure the effect of light intensity on oxygen production in leaf discs, the air spaces within the leaf discs were infiltrated with sodium bicarbonate solution so they sunk, then were distributed between three beakers. As the leaf discs photosynthesized, oxygen was produced in the air spaces, causing them to float (Campbell et al. 2006:183-4). The three beakers were placed in conditions of varying light intensities and recordings were taken to determine the amount of leaf discs floating in each at 30-second intervals for 12 minutes.

Initially a hole-punch was used to cut out 30 uniform leaf discs to be used in the experiment. To infiltrate the air spaces in the leaf discs, the discs were put in a 30mL syringe, which was pulled to draw in 27 mL of sodium bicarbonate solution, leaving a 3 mL air space. The end of the syringe was sealed and a negative pressure system was created by pulling back the handle further. The syringe was shaken simultaneously, causing the gas within the leaf discs to be pulled out and bubble to the surface. This process was repeated several times until most of the leaf discs were infiltrated with the solution and sunk to the bottom.

Ten of the leaf discs were then removed and placed into each of three 100 mL beakers, which were topped up with 20 mL of bicarbonate solution. One beaker was placed in the dark to act as a control and, as photosynthesis light reactions do not occur when light isn't present, the leaf discs were not expected to float (Campbell et al. 2006:198). The purpose of this control beaker was to account for any other factors that could cause the leaf discs to float. The second and third beakers were placed 150 mm and 200 mm respectively from a 150 W light source. A large beaker of water separated the two beakers from the light source and absorbed the heat to prevent an increase in temperature from affecting the results.

2.3 Gas Exchange by Plants and Animals

In order to determine the effect of light on a combination of respiring and photosynthesizing organisms, eight beakers filled with pond water were set out in the following manner. Four beakers, one containing just pond water, one containing two snails, one containing a stem of elodea (an aquatic plant), and one containing both a stem of elodea and two snails, were placed in a well-lit area. The other four beakers, containing the same combination of specimens, were placed in a dark cupboard. The purpose of placing four beakers in the dark was to measure the carbon dioxide concentration in the beakers without photosynthesis occurring, as light is required for that process (Campbell et al. 2006:181).

To each of the eight beakers, sufficient Bromothymol Blue indicator was added to turn the water vivid blue. Bromothymol Blue is a harmless vegetable die that turns yellow when in the presence of an acid (Rhodes 2006:25). Carbon dioxide dissolves in water and leads to acidification, so the die was used as an indicator of the carbon dioxide concentrations in the water in the beakers (Rhodes 2006:25-7). The beakers

were set up at 07:40 am and changes in the watercolour and conditions were observed five hours later, at approximately 12:40 pm.

3.0 Results

3.1 Oxygen Consumption in Respiration

Table1: Distance die moved due to respiration of germinating mung bean sprouts.

Time (minutes)	Respiration Chamber (mm)		Compensation Chamber (mm)		Net Movement in past minute (1-2) (mm)	Cumulative Net Movement (mm)
	Measurement (mm)	Movement in past minute (1) (mm)	Measurement (mm)	Movement in past minute (2) (mm)		
0	15		20			0
1	33	18	15	-5	23	23
2	47	14	14	-1	15	38
3	61	14	11	-3	17	55
4	79	18	9	-2	20	75
5	95	16	8	-1	17	92

The movement of the die in both the respiration chamber and compensation chamber was measured every one minute for five minutes and the results can be seen in table 1. The total net movement of the dye (a function of the total movement in both the respiration and compensation chambers) was 92 mm. Over the five-minute period the dye moved inwards, towards the mung beans, a total of 80 mm as a result of reduced air pressure in the respiration chamber and outwards, away from the pebbles, a total of 12 mm as a result of increased air pressure in the compensation chamber. The cumulative net movement (a function of the respiration and compensation chamber measurements for each minute) shows a steady shift in the dye as a result of increased air pressure within the respirometer. As can be seen in figure 1, a linear relationship exists between the time in minutes and the net movement of dye in millimetres. On average, the dye moved 18 mm per minute, representing a relatively consistent increase in the volume of gas within the respirometer, as was expected.

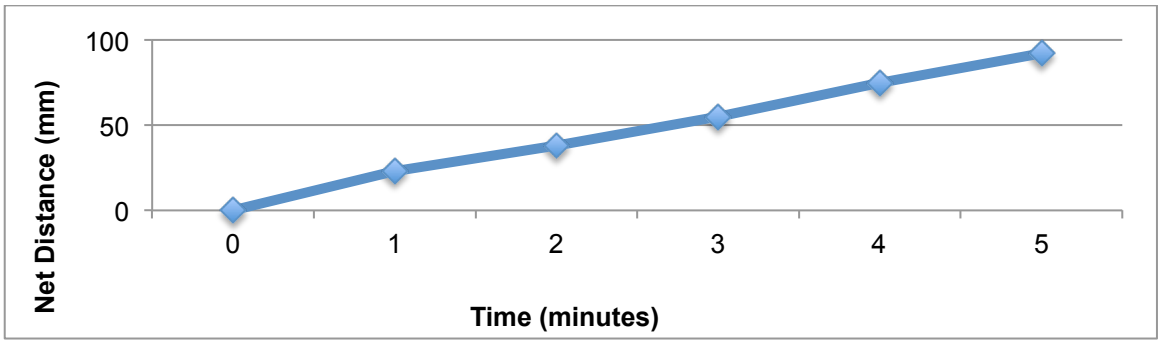

Figure 1: Distance dye moved as a result of respiring mung beans.

3.2 Effect of Light on Oxygen Production in Photosynthesis

Table 2: Number of leaf discs floating due to production of oxygen during photosynthesis under varying light intensities.					
Time (mins)	**Floaters 150mm from light**	**Floaters 200mm from light**	**Time (mins)**	**Floaters 150mm from light**	**Floaters 200mm from light**
0	0	0	6.5	8	6
0.5	0	0	7	8	6
1	0	0	7.5	8	6
1.5	0	0	8	8	6
2	0	0	8.5	9	6
2.5	0	1	9	9	6
3	1	1	9.5	9	6
3.5	4	1	10	10	7
4	5	1	10.5	10	7
4.5	6	3	11	10	7
5	6	3	11.5	10	7
5.5	8	4	12	10	7
Note: No leaf discs were floating after 12 minutes in the beaker placed in the dark.					

At the end of the 12-minute observation time in the experiment designed to measure oxygen production during photosynthesis, all of the leaf discs in the beaker 150 mm from the light source were floating, but only seven of the original ten were floating in the beaker 200 mm away from the light source. It was noted that the leaf discs in the beaker 200 mm from the light source showed a noticeable lag in the time they took to float, compared to that in the beaker 150 mm from the light source, as can be seen in figure 2.

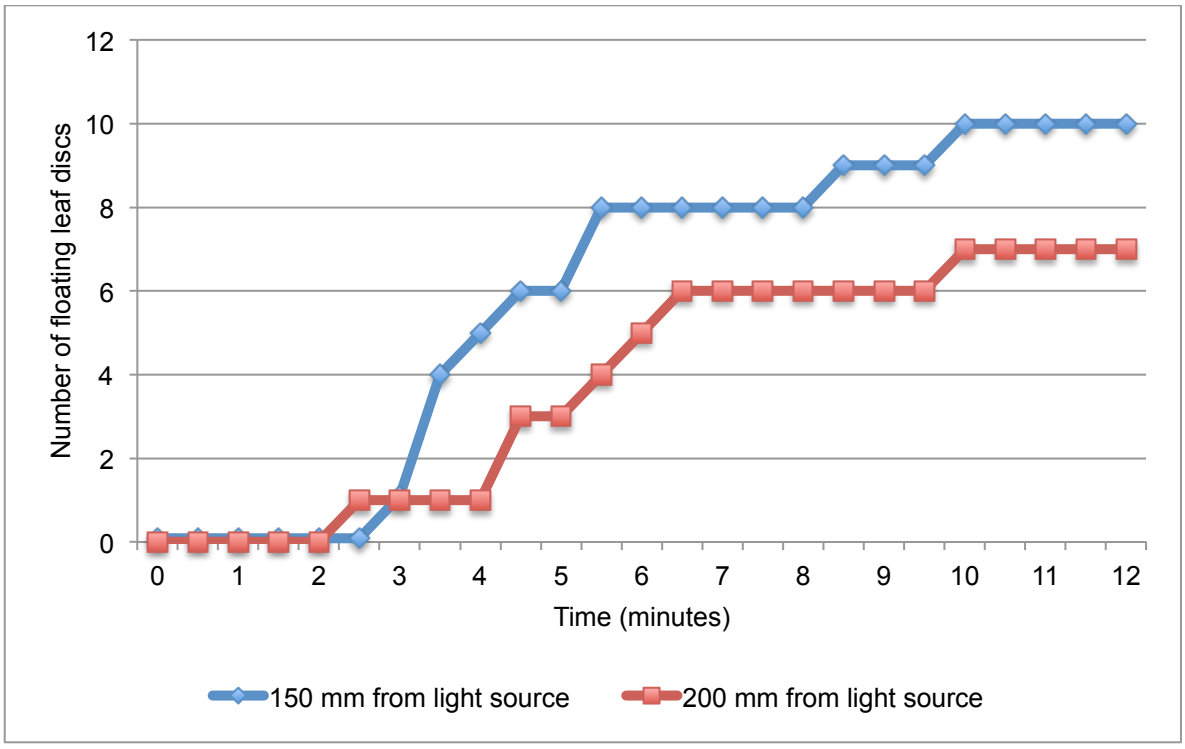

Figure 2: Number of leaf discs floating due to production of oxygen during photosynthesis under varying light intensities.

For example, when there were four leaf discs floating in the first beaker there was only one in the second, when there were six discs floating in the first beaker, there were only three in the second, and when there were there were eight discs floating in the first beaker there were only four in the second. From this pattern it is easy to recognise the effect of light intensity on the rate of oxygen production from photosynthesis in the leaf discs. Additionally, none of the leaf discs in the beaker placed in the dark were floating at the end of the 12-minute observation period.

3.3 Gas Exchange by Plants and Animals

During the reaction designed to observe the results of gas exchange by various organisms, colour changes and general observations were noted and can be seen in table 3. As organisms only respire and don't photosynthesise in the dark, the concentrations of carbon dioxide in the four beakers in the dark depended only on the respiration of the organisms in the beakers (Campbell et al. 2006:160,182). Of the four beakers in the dark, the beaker with pond water was the darkest (and therefore had the lowest concentration of carbon dioxide), the beaker with the elodea was slightly lighter, the beaker with just the snails was slightly lighter again, and the beaker with both the snails and the elodea was the lightest (and therefore had the highest concentration of carbon dioxide). As plants photosynthesise in light, both photosynthesis and respiration was occurring in some of the light beakers, which affected the concentrations of carbon dioxide (Campbell et al. 2006:160,182). Of the beakers in the light, the beaker with only pond water was the darkest in colour (and therefore had the lowest carbon dioxide concentration), the beaker with only the elodea appeared to be the same dark colour, the beaker with both the snails and the elodea was slightly lighter, and the beaker with only the snails was the lightest in colour (and therefore had the highest concentration of carbon dioxide). The above observations are outlined in figure 3, which shows the various beaker combinations arranged from the lowest concentration of carbon dioxide to the highest. As can be seen in the observations in table 3, one or two of the snails in three of the beakers appeared to have gone into a dormant phase where they shut themselves into their shells. This could have had an effect on the levels of respiration occurring in those beakers.

LOWEST CONCENTRATION OF CO_2
Pond Water in **Dark** Pond Water in **Light** Elodea in **Light**
Elodea in **Dark**
Snails & Elodea in **Light**
Snails in **Dark** Snails in **Light**
Snails & Elodea in **Dark**
HIGHEST CONCENTRATION OF CO_2

Figure 3: Different concentrations of carbon dioxide in beakers of varying specimens.

Table 3: Changes in acid concentration over time in beakers containing various respiring and photosynthesizing organisms in different light conditions.			
Specimen(s)	**Colour Change**		**General Observations**
	Dark	**Light**	
Water	Very Dark Blue	Very Dark Blue	The water remained dark blue in both beakers, as there were no organisms using or producing carbon dioxide in the water.
Elodea	Dark Blue	Very Dark Blue	The beaker in the dark was visibly lighter but there appeared to be no difference in the watercolour of the beaker in the dark and the beakers containing just pond water.
Snails	Light Blue	Light Blue	In the beaker in the light both snails were awake and appeared normal, however, in the beaker in the dark, one snail appeared to be in a dormant phase, closed into its shell.
Snails & Elodea	Very Light Blue	Blue	In the beaker in the light, one of the two snails appeared to be in a dormant condition. In the beaker in the dark, both were.

4.0 Discussion

4.1 Oxygen Consumption in Respiration

All plant and animal cells undergo the process of respiration, by which organic compounds are broken down to produce energy stored as ATP (Campbell et al. 2006:160-1). This cellular process, which occurs in organelles called mitochondrion, uses oxygen and yields carbon dioxide as a by-product (Campbell et al. 2006:161). This was noted in the observed decrease in air pressure caused by the consumption of oxygen by germinating mung beans in a closed (sealed) system, which was indicated by the movement of a drop of dye over five minutes (moved 92 mm in total). Oxygen is used during cellular respiration as the terminal electron acceptor in the electron transport chain (Campbell et al. 2006:170-2). Through its strong electronegativity (affinity for electrons), oxygen drives the flow of electrons down a chain of proteins and, at the end, combines with the electrons and two hydrogen ions to form water (Campbell et al. 2006:179). During respiration, the production of carbon dioxide also occurs from the break down of the pyruvate molecules before and during the Krebs cycle stage (Campbell et al. 2006:168). To ensure the results from the experiment depicted only the consumption of oxygen during respiration, potassium hydroxide pellets were utilised as they reacted with carbon dioxide gas and removed it from the air within the chamber (Portugual 2008:3495). The control (the compensation chamber) ensured that outside factors were taken into consideration such as changes in temperature, which would affect the internal air pressure within the chambers (Belonuchkin 2000:44).

4.2 Effect of Light on Oxygen Production in Photosynthesis

Photosynthesis is the process that occurs in organelles called chloroplasts in the cells of the green parts of plants (Campbell et al. 2006:182). Plants use the process of photosynthesis to convert light energy into chemical energy, which is stored in the bonds of organic compounds (sugars) that are produced (Campbell et al. 2006:182-3). During this process carbon dioxide and water are used to synthesise these sugars and oxygen is produced as a by-product during the light reactions stage (Campbell et al. 2006:183). During this stage oxygen remains after light separates it from the electrons and hydrogen of water molecules, which are then harvested and stored in NADPH (Campbell et al. 2006:184). The intensity of the light available affects the rate of photosynthesis and when no light is available, the light reactions ceases to occur (Rascher & Nedbal 2006:672-3). However, the dark reactions can continue to fix carbon dioxide and produce sugars via the Calvin cycle, using the products from the light reactions (Rascher & Nedbal 2006:673). During the experiment involving the observing the production of oxygen during photosynthesis, it was noted that higher light intensities markedly increased the rates of photosynthesis. This was exhibited by the air spaces of the leaf discs in the beaker closest to the light filling with oxygen quicker, thus causing the discs to float to the surface faster, than those in the second beaker. During the experiment, applying negative pressure to the leaf discs caused the gas in the air spaces to be 'pulled' out and bubble to the surface, resulting in the discs sinking. However, not all of the leaf discs sunk initially and this could have been due to the need for more pressure as a result of the strong structure of the cell walls of plants (Campbell et al. 2006:118). Additionally, not all leaf discs in the beaker 200 mm from the light were floating at the end of the 12-minute observation period. Although this could be attributed to the slower rate of oxygen production due to the lower light intensity, it may have also been a result of the leaf discs being damaged after exposure to such negative pressure. The leaf discs in the control beaker that was placed in a cupboard, did not produce oxygen and float, as the light reactions of photosynthesis do not occur in the dark (Rascher & Nedbal 2006:672).

4.3 Gas Exchange by Plants and Animals

Plants and animals both undergo respiration to produce energy, which involves the consumption of oxygen and the production of carbon dioxide (Campbell et al. 2006:160). When sufficient light is available, plants also undergo photosynthesis to produce energy stored in organic compounds, which uses carbon dioxide and results in oxygen as a by-product (Campbell et al. 2006:182-3). During the experiment that involved noting varying organisms' effect on carbon dioxide concentrations, the highest concentration of carbon dioxide was observed in the beaker in the dark with both elodea and snails in it. This is because all of the organisms were undergoing respiration for energy production and were therefore producing carbon dioxide (Campbell et al. 2006:161). However, none were consuming this carbon dioxide via photosynthesis, due to the lack of light (Rascher & Nedbal 2006:672). Where the elodea was places in the light, there appeared to be no net increase in the carbon dioxide levels as the carbon dioxide was being consumed by the elodea, which was also photosynthesising. Where there were plants and animals both respiring and photosynthesising, the net concentration of carbon dioxide continued to increase as the respiration of both the snails and elodea occurred in greater levels than just the photosynthesis of the elodea. The snails used in the experiment produced more carbon dioxide than the elodea did as a result of higher levels of respiration. This is because respiration is greater in cells of organisms that require more energy for general processes (Campbell et al. 2006:160-1).

5.0 References

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PLEASE NOTE: I had some difficulties with Safe Assign and kept getting error messages when I tried to attach my assignment. I have now managed to submit it to Safe Assign but the report did not come back in time to submit it with the assignment. Apologies.