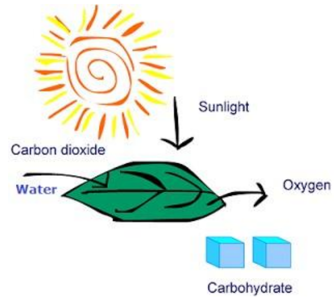
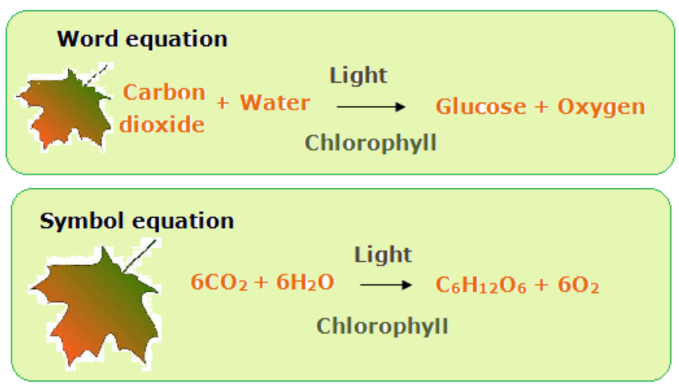
04 – Plant nutrition
#38 The equation for photosynthesis



Photosynthesis is the fundamental process by which plants manufacture food molecules (**carbohydrates**) from raw materials **CO_2** and **H_2O)** using **energy** from **light**.

1.The equation for photosynthesis

Photosynthesis



- The raw materials are CO_2, H_2O and light energy.
- The products are glucose (starch) and O_2

2. The process of photosynthesis

- Green plants take in **CO_2** through their leaves (by **diffusion**).
- **H_2O** is absorbed through plants' roots (by **osmosis**), and transported to the leaf through **xylem** vessels.
- **Chlorophyll** traps **light energy** and absorbs it.
- This energy is used to break up H_2O molecules, than to bond hydrogen and CO_2 to form **glucose**.
- Glucose is usually changed to **sucrose** for transport around the plant, or to **starch** for storage.
- **O_2** is released as a waste product, or used by plant for respiration.
- In this process, **light energy** is converted to **chemical** energy for the formation of glucose and its subsequent storage.

Video: What is photosynthesis?
https://www.youtube.com/watch?v=WHMLq3bqGwk

#39 Photosynthesis investigations - Principles and Starch test

(a) (b)

A leaf before (a)
and after (b) starch test.

Experiments can be used to find out what factors (CO_2, light, cholorophyll) are needed for photosynthesis. But first of all you need to **destarch** the plants. To be certain that they are thoroughly destarched, **test** a leaf for **starch** before you begin your investigation.

Principles of investigations

1. Investigations need controls

- **Control** plant (or leave) has all substances it needs.
- **Test** plant lacks one substance (light/chlorophyll/CO_2)

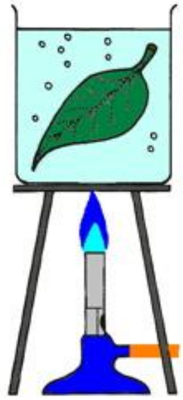
2. Plants must be destarched

- It is very important that the leaves you are testing should **not** have any **starch** in them at the beginning of the experiment.
- So, first of all, you must destarch the plants. Leave them in the **dark** for 48 hours. The plants use up all stores of starch in its leaves.

3. Starch test with Iodine solution

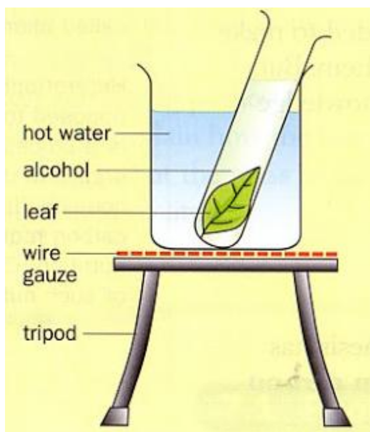
- After a few hours, carry out the starch test on both plants: **Iodine solution** is used; a blue-black colour on the leave is positive.

- **Boil the leaf in water** for 30 second. This kill the cells in the leaf à break down the membrane à iodine solution gets through cell membrane to reach **starch** inside the chloroplasts and react with them.



Boil the leaf in water.

- **Boil the leaf in alcohol** (ethanol) in a water bath: The **green colour** of the leaf and the brown iodine solution can look black together, so you need to remove **chlorophyll** by **dissolving** it out with **alcohol**. Leave it until all the chlorophyll has come out of the leaf.



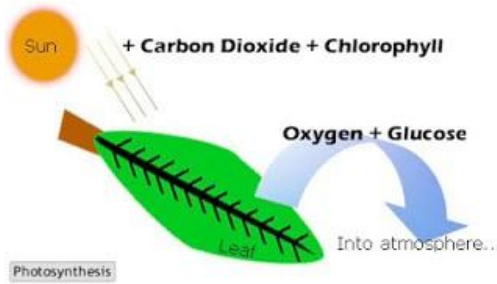
Boil the leaf in alcohol.

- **Rinse the leaf in water**: Boiling the leaf in ethanol makes it brittle, the water softens it.
- Spread the leaf out on a **white** tile à easy to see the result.
- **Add iodine solution** to the leaf à blue- black colour is positive, starch is present.

A leaf before (on the left) and after (on the right) starch test.

Additional resource: sjiiscience.blogspot.com

#40 Photosynthesis investigations – chlorophyll, CO2, light tests



Investigations to see if chlorophyll, light and CO2 are needed for photosynthesis.

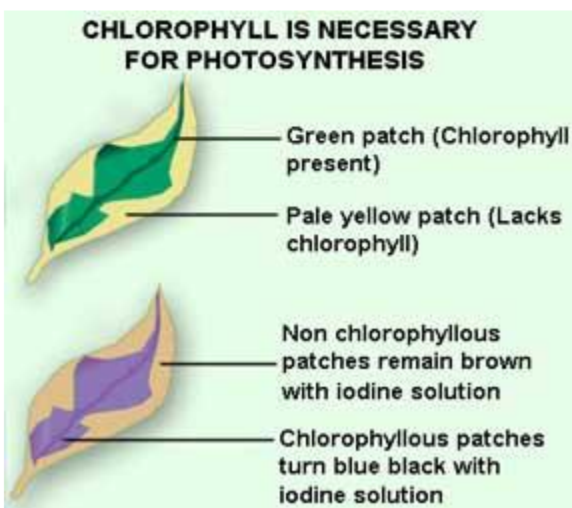
1. Chlorophyll is necessary for photosynthesis

Process

- Take a potted plant with **variegated** (green and white) leaves.
- **Destarch** the plant by keeping it in complete darkness for about 48 hours.
- Expose the plant to the **sunlight** for a few days.
- Test one of the leaves for **starch** with iodine solution.

Observations

- Areas with previously **green** patches test **positive** (turn blue black).
- Areas with previously pale **yellow** patches test **negative** (remain brown).



Conclusion

- Photosynthesis takes place only in green patches because of the presence of **chlorophyll**.
- The pale yellow patches do not perform photosynthesis because of the absence of chlorophyll.

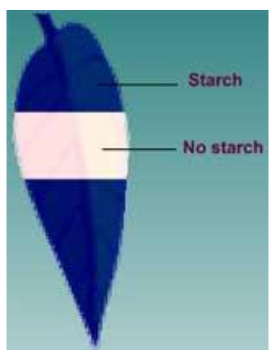
2. Light is essential for photosynthesis

Process

- Take a potted plant.
- **Destarch** the plant by keeping it in complete darkness for about 48 hours.
- Test one of it leaves for starch, to check that is does not contain any.
- Fix a leaf of this plant in between two strips of a thick paper on leaf.
- Place the plant in light for a few days.
- Remove the cover from the leaf and test it for starch.

Observations

Positive starch test will be obtained only in the portion of the leaf exposed to light and negative test in parts with paper strip.

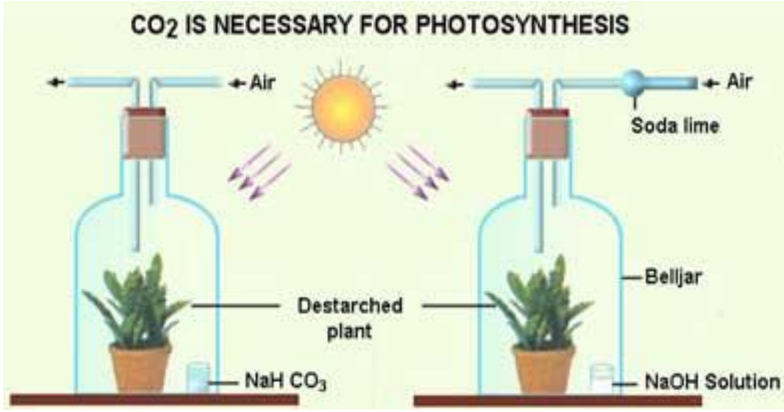


Conclusion
Light is necessary for photosynthesis.

3. Carbon dioxide is essential for photosynthesis

Process

- Take two destarched potted plants.
- Cover both the plants with bell jars and label them as A and B.
- Inside Set-up A, keep **$NaHCO_3$** (sodium bicarbonate). It produces CO_2.
- Inside Set-up B, keep **NaOH** (Sodium hydroxide). It absorbs CO_2.
- Keep both the set-ups in the sunlight at least for 6 hours.
- Perform the starch test on both of the plants.



Observations

Leaf from the plant in which **$NaHCO_3$** has been placed gives **positive** test.
Leaf from the plant in which **NaOH** has been kept give **negatif** test.

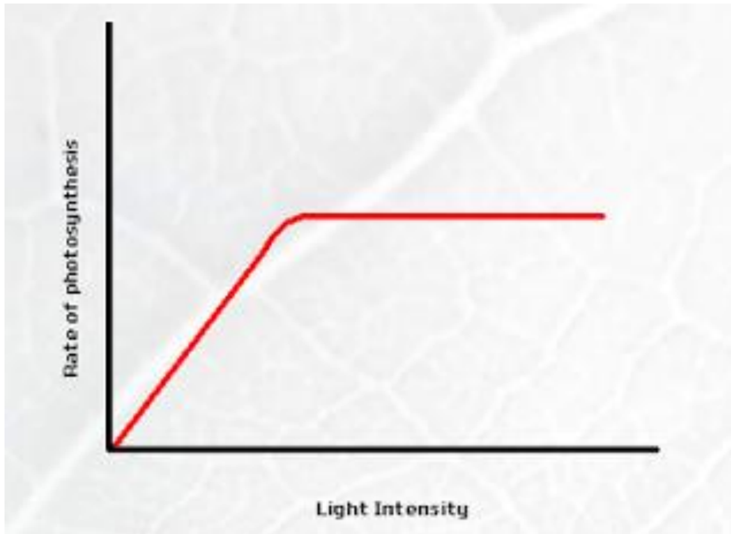
Conclusion

Plant in Set up A gets CO_2 whereas plant in Set-up B does not get CO_2.
It means CO_2 is must for photosynthesis.

Source: **[mastermindtutor.com]**

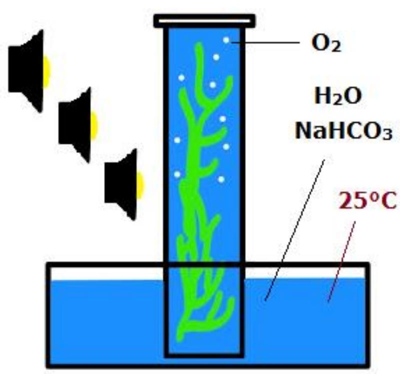
#41 Effect of Light intensity on the rate of Photosynthesis

Plants need light energy to make the chemical energy needed to create carbohydrates. Increasing the light intensity will boost the speed of photosynthesis. However, at high light intensities the rate becomes constant.



Experiment

- Place a pond weed Elodea upside in a test tube containing water.
- Place the tube in a beaker of fresh water at 25°C. This helps to maintain a constant temperature around the pond weed.
- Place excess sodium bicarbonate ($NaHCO_3$) in the water to give a constant saturated solution of CO2.
- Place the lamp (the only light source) at distance from the plant.



- Count the number of oxygen bubbles given off by the plant in 1 minute period. This is the rate of photosynthesis at that particular light intensity.
- The gas should be checked to prove that it is indeed oxygen - relights a glowing splint.

- Repeat at different light intensities by moving the lamp to different distances.

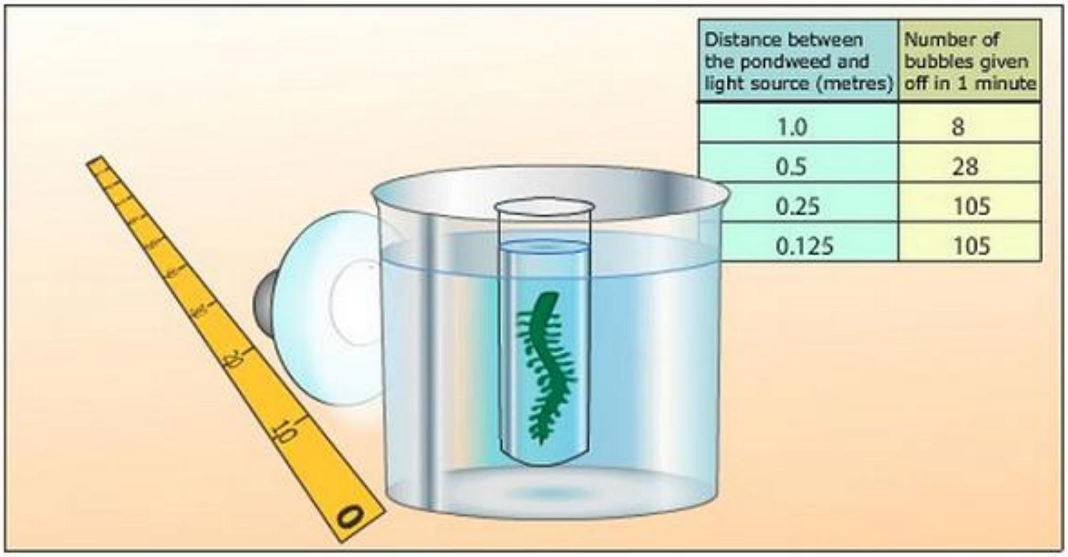
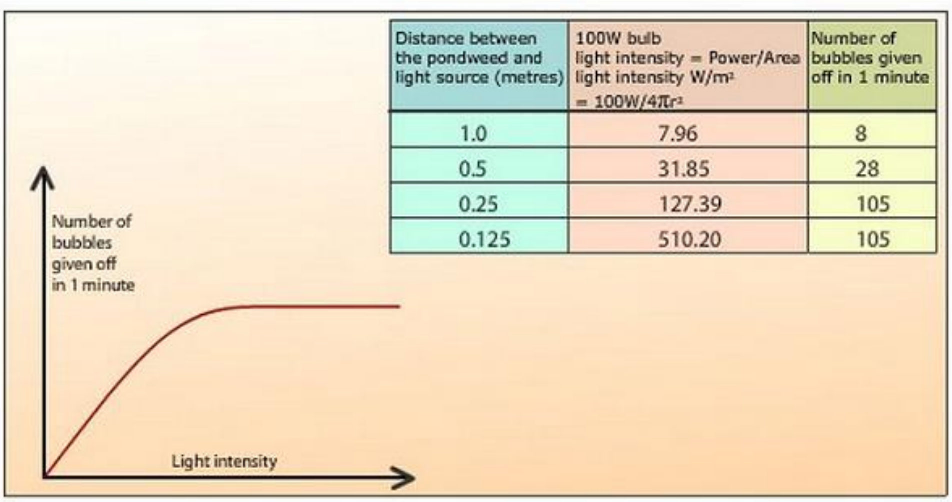


Photo from passmyexams.co.uk

- Graph the results placing light intensity on the x-axis.



Explanation

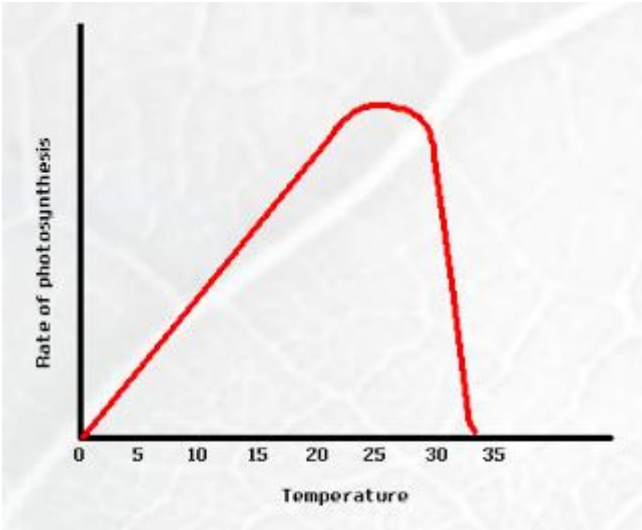
- **Light energy** absorbed by chlorophyll is converted to ATP and H+
- At very low light levels the plant will be respiring only not photosynthesising.
- As the **light intensity increases**, the **rate** of photosynthesis **increases**. However, the rate will not increase beyond a certain level of light intensity.

- At high light intensities the rate becomes **constant**, even with further increases in light intensity, there are no increases in the rate.
- The plant is unable to harvest the light at these high intensities and the chlorophyll system can be damaged by very intense light levels.

Additional sources: **skoool.ie**
passmyexams.co.uk

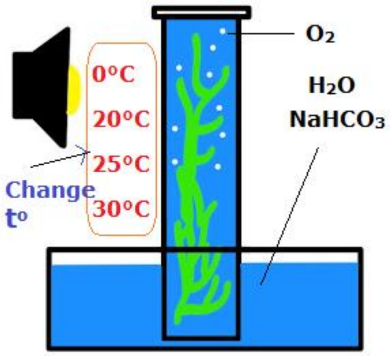
#42 Effect of Temperature on the Rate of Photosynthesis

When the **temperature** rises the rate of photosynthesis rises also. There is an **optimum** temperature at which the rate of photosynthesis is maximum. Beyond this temperature, the reaction quickly comes to a halt.



Experiment

- Place a pond weed Elodea upside in a test tube containing water at 25°C.
- Place the tube in a beaker of fresh water.
- Place excess sodium bicarbonate ($NaHCO_3$) in the water to give a constant saturated solution of CO2.
- Place the lamp (the only light source) at a fixed distance from the plant.
- Maintain the room temperature at 20°C.

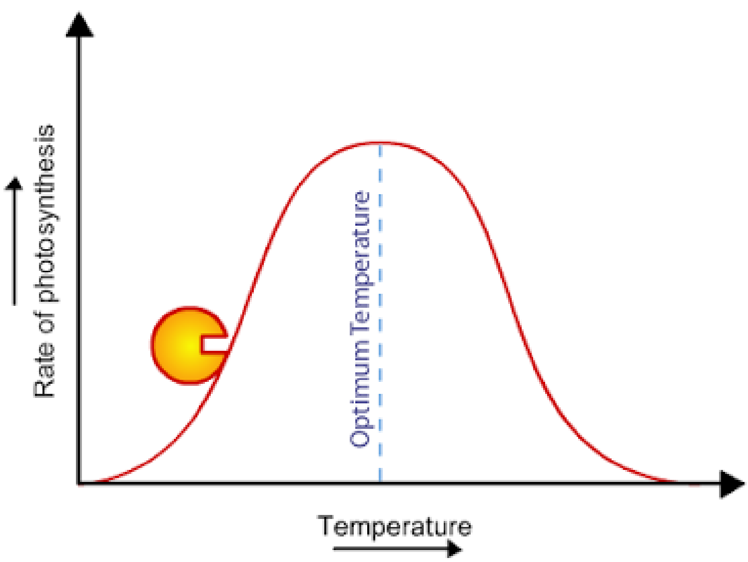


- Count the number of oxygen bubbles given off by the plant in a one - minute period. This is the rate of photosynthesis at that particular temperature.

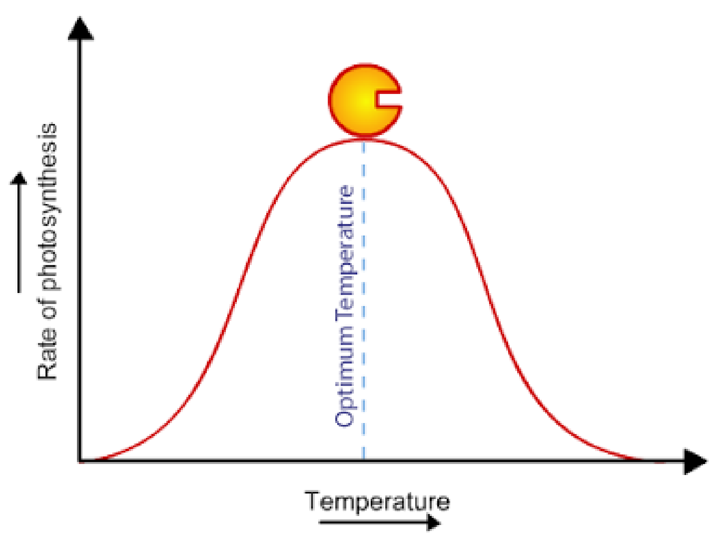
- The gas should be checked to prove that it is indeed oxygen - relights a glowing splint.
- Repeat at different temperatures: 0°C - surround the beaker with an ice jacket; greater than room temperature (25°C, 30°C, 35°C, 40°C, 45°C, etc.,) by using a hot plate.
- Graph the results placing temperature on the x-axis.

Explanation

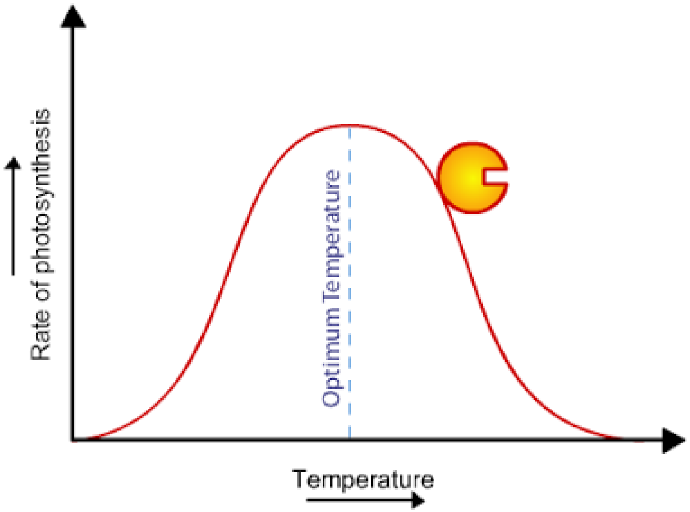
- At low temperature, the enzyme does not have enough energy to meet many substrate molecules, so the reaction is slowed.
- When the temperature rises, the particles in the reaction move quicker and collide more, so the rate of photosynthesis rises also.



- At the optimum temperature, the enzyme is most efficient and the rate if maximum.



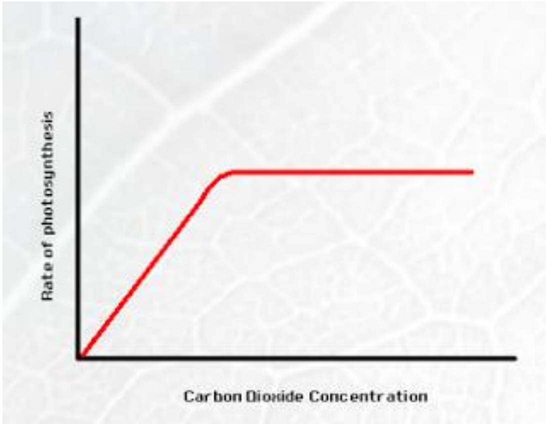
- At temperatures above 40°C the rate slows down. This is because the enzymes involved in the chemical reactions of photosynthesis are temperature sensitive and destroyed (denatured) at higher temperatures.



Additional sources : skoool.ie
passmyexams.co.uk
woisd.net

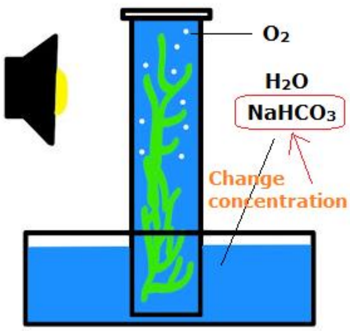
#43 Effect of CO_2 on the Rate of Photosynthesis

When the concentration of CO_2 is low the rate of photosynthesis is also low. (the plant has to spend time waiting for more CO_2 to arrive). Increasing the concentration of CO_2 increases the rate of photosynthesis.

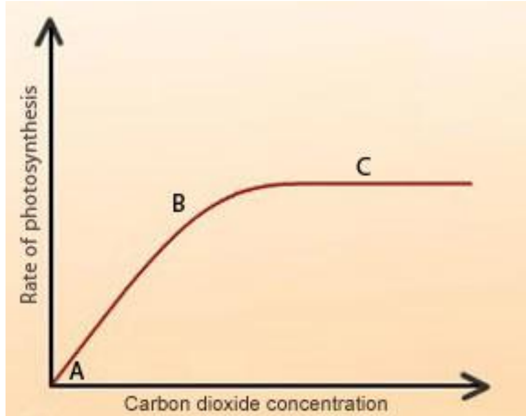


Experiment

- Place a pond weed Elodea upside in a test tube containing water at 25°C.
- Place the tube in a beaker of fresh water.
- Place excess sodium bicarbonate ($NaHCO_3$) in the water to give a constant saturated solution of CO_2.
- Place the lamp (the only light source) at a fixed distance from the plant.
- Maintain the room temperature at 20°C.



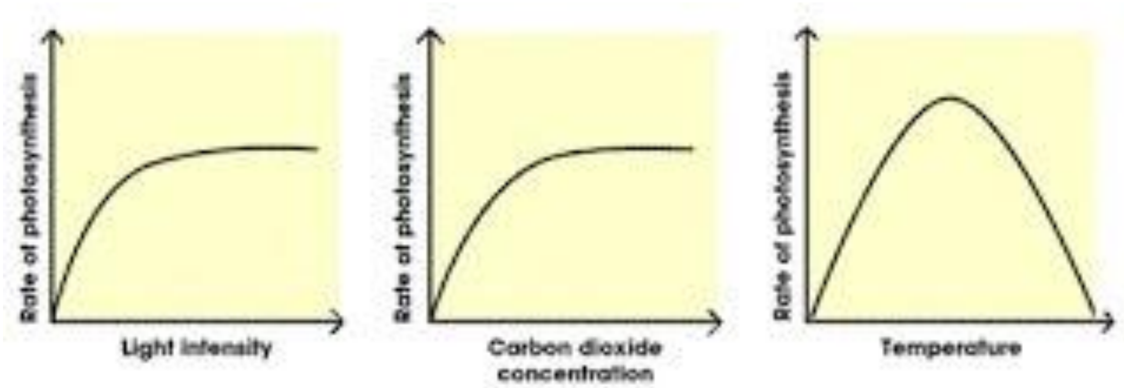
- Count the number of oxygen bubbles given off by the plant in a one - minute period. This is the rate of photosynthesis at that particular concentration of CO_2.
- The gas should be checked to prove that it is indeed oxygen - relights a glowing splint.
- Repeat at different lower CO_2 concentrations by using different dilutions of a saturated solution.
- Graph the results placing CO_2 concentration on the x-axis.



Explanation

- The rate of photosynthesis **increases linearly** with increasing CO_2 concentration (from point A to B).
- The rate falls gradually, and at a certain CO_2 concentration it stays constant (from point B to C). Here a rise in CO_2 levels has **no effect** as the other factors such as light intensity become limiting.

#44 Limiting factors in photosynthesis

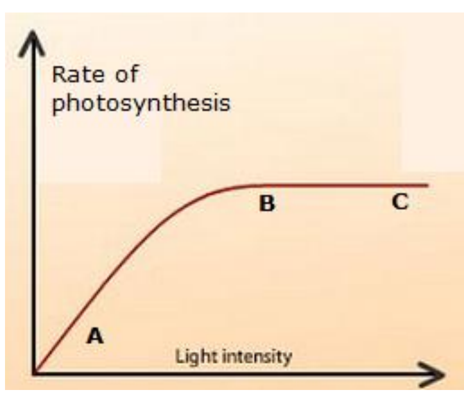


Limiting factor is something present in the environment in such **short supply** that it restricts life processes. Three factors can limit the speed of photosynthesis - **light** intensity, **carbon dioxide** concentration and **temperature**.

If a component is in low supply then productivity is prevented from reaching maximum.

Sunlight

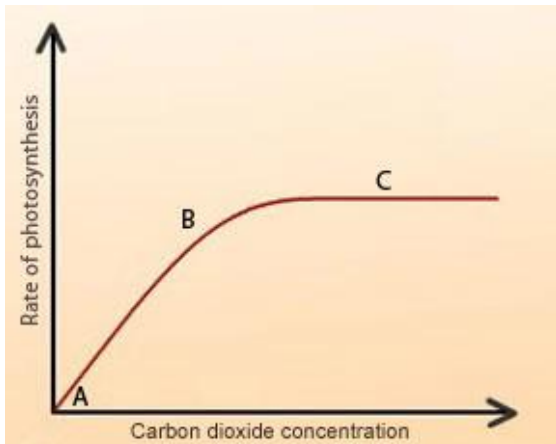
- Light energy is vital to the process of photosynthesis. It is severely limiting at times of partial light conditions, e.g. dawn or dusk.
- As light intensity increases, the rate of photosynthesis will increase, until the plant is photosynthesising **as fast as it can**. At this point, even if light becomes brighter, the plant cannot photosynthesise any faster.



- Over the first part of the curve (**between A and B**), light is a **limiting factor.** The plant is limited in how fast it can photosynthesise because it does not have enough light.
- Between B and C, light is not a limiting factor. Even if more light is shone on the plant, it still cannot photosynthesise any faster.

Carbon dioxide

- In photosynthesis CO_2 is a key limiting factor. The usual atmospheric level of CO_2 is 0.03%. In perfect conditions of water availability, light and temperature this low CO_2 level holds back the photosynthetic potential.
- The more CO_2 a plant is given, the faster it can photosynthesise up to a point, but then a maximum is reach.



Temperature

The chemical reactions of photsynthesis can only take place very slowly at low temperature, so a plant can photosynthesise faster on a warm day than on a cold one.

#45 Optimum conditions for photosynthesis in Green house

When plants are growing outside, we can not do much about changing the conditions that they need for photosynthesis. But if crops are grown in glasshouses, then it is possible to control conditions so that they are photosynthesising as fast as possible.

CO_2 enrichment

CO_2 concentration can be controlled. CO_2 is often a limiting factor for photosynthesis, because its natural concentration in the air is so very low (0.04%). In a closed glasshouse, it is possible to provide extra CO_2 for the plants, e.g. by burning fossil fuels or releasing pure CO_2 from a gas cylinder.

Optimum light

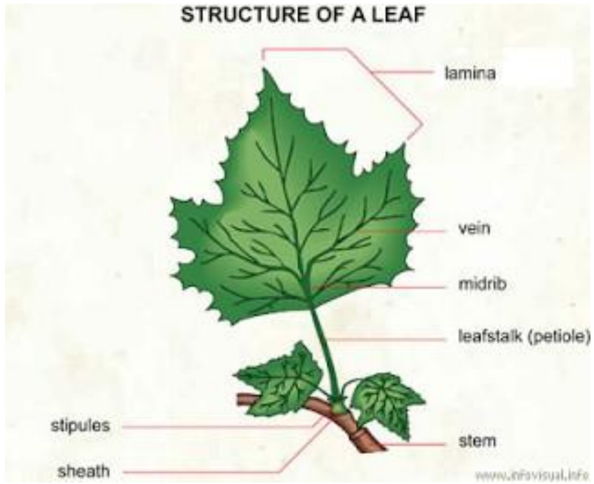
Light also can be controlled. In cloudy or dark conditions, extra artificial lighting can be provided, so that light is not limiting the rate of photosynthesis. The kind of lights that are used can be chosen carefully so that they provide just the right wavelengths that the plants need.

Optimum temperature

In some countries where it is too cold for good growth of some crop plants, the heated greenhouses can be used. This is done, for example, with tomatoes. The temperature in the glasshouse can be kept at the optimum level to encourage the tomatoes to grow fast and strongly, and to produce a large yield of fruit that ripens quickly.

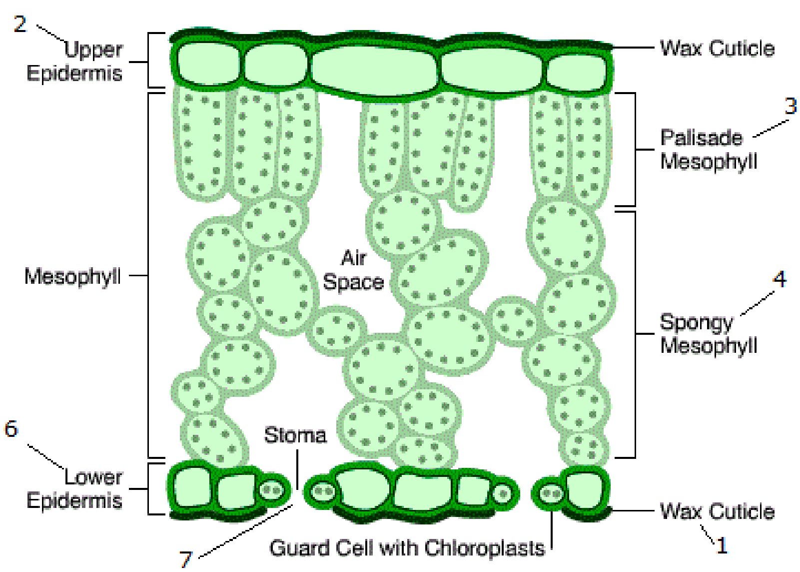
The temperature can be raised by using a heating system. If fossil fuels are burned, there is also a benefit from the CO_2 produced.

#46 Leaf structure



The leaf consist of a broad, flat part called the **lamina**, which is joined to the rest of the plant by a leaf stalk or **petiole**. Running through the petiole are **vascular bundles**, which then form the **veins** in the leaf.

Although a leaf looks thin, its is made up of **several layers** of cells. You can see these if you look at a transverse section (cross-section) of a leaf under a microscope.



1. Cuticle:

- made of **wax** – waterproofing the leaf
- secreted by cells of the upper epidermis

2. Upper epidermis

- thin and transparent – allows **light** to pass through
- **no chloroplasts** are present
- act as a **barrier** to disease organisms

3. Palisade mesophyll

- main region for **photosynthesis**
- cells are **columnar** (quite long) and packed with **chloroplasts** to trap light energy
- receive CO_2 by diffusion from air spaces in the spongy mesophyll

4. Spongy mesophyll

- cells are more **spherical** and loosely packed
- contain chloroplasts, but not as many as in palisade cells
- **air spaces** between cells allow gaseous exchange – co_2 to the cells, o_2 from the cells during photosynthesis

5. Vascular bundle

- this is a leaf **vein**, made up of xylem and phloem
- **xylem** vessels bring **water** and **minerals** to the leaf
- **phloem** vessels transport **sugars** and **amino acids** away (translocation)

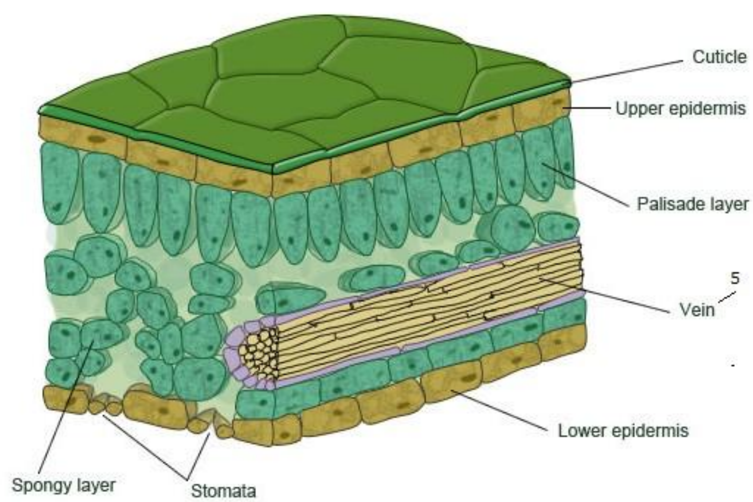


Photo credit: Pass My Exams

6.Lower epidermis

- acts as a **protective** layer
- **stomata** are present to regulate the loss of **water vapour** (transpiration)
- site of **gaseous exchange** into and out of the leaf

7. Stomata

- each stomata is surrounded by a pair of **guard cells**
- guard cells – control whether the stoma is **open** or **closed**
- water vapour passes out during **transpiration**
- CO_2 diffuses in and **O_2** diffuses out during **photosynthesis**

#47 Plant's mineral requirements and fertilisers

Plants need minerals for healthy growth.

Plant is in need for **mineral ions** to control chemical activities, grow, and produce materials. The most important minerals are **Magnesium** ions and **Nitrates**.

1.Importance of nitrate and magnesium ions

	Nitrogen	Magnesium
Mineral salt	Nitrates (NO_3^-) or Ammonium (NH_4^+) ions	Magnesium (Mg^{++}) ions
Why needed	To make proteins	To make chlorophyll
Deficiency	Weak growth, yellow leaves	Yellowing between the veins of leaves

a. Nitrates

- plants absorb nitrate ions from the soil, through their root hairs
- nitrate ions combine with glucose -----> **amino acids**
- amino acids bond together -----> **protein**
- **deficiency** causes poor growth, especially of leaves. The stem becomes weak, lower leaves become yellow and die, while upper leaves turn pale green

Nitrates deficiency: Growth severely restricted, few stems; yellowing of older foliage.

b.Magnesium

- plants absorb magnesium ions from the soil solution
- used for the manufacture of **chlorophyll**
- each chlorophyll contains one magnesium atom
- **deficiency** makes leaves turn yellow from the bottom of the stem upwards and eventually stops photosynthesis

Magnesium deficiency in potato plant.

(Growth fairly normal; foliage slightly pale; older leaflets develop central necrosis, turn yellow or brown and wither prematurely).

Magnesium deficiency: yellowing between the veins of leaves.

2. Nitrogen fertilisers

Sometimes the soil is lacking of the mineral ions needed, this problem can be solved by adding fertilisers to the soil. Fertilisers are chemical compounds rich in the mineral ions needed by the plants. They help the plants grow faster, increase in size and become greener, they simply make them healthier and **increase** the **crop yield**.

Ammonium Nitrate fertiliser

Intensive farming (repeatedly using the same land fro crops) removes nitrates from the soil. These need to be replaced to prevent a drop in yield. Nitrates can be replaced in 3 ways:

- applying animal **manure**
- **crop rotation** – growing leguminous plants such as peas, beans and clover every 2 or 3 years: these plants develop root nodules containing nitrogen-fixing bacteria, and the roots are ploughed into the soil, boosting nitrate levels
- adding artificial **fertilisers** such as ammonium nitrate

Danger of overuse

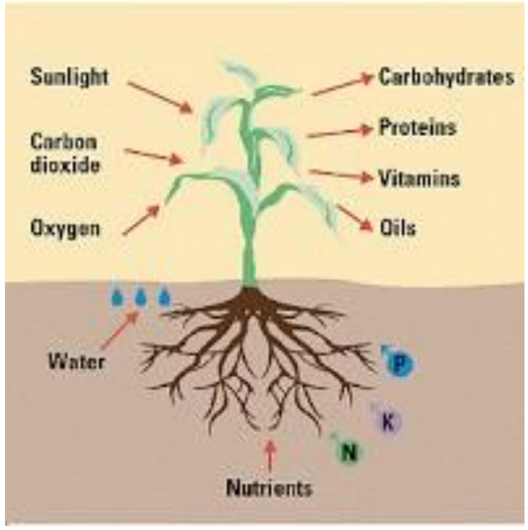
Apply too much nitrogen fertiliser ----> **water** is drawn out of plant roots (osmosis) ----> plant wilt/die.

Eutrophication:
Nitrates can be **leached** out of the soil and enter a nearby **river** polluting it, creating a layer of green **algae** on the **surface** of it causing lack of **light** in the river thus preventing the aqua plants photosynthesising ----> **death** of algae ----> decomposers (**bacteria**) multiply and decay, respire using $\mathbf{O_2}$ ----> death of **aquatic animals** from lack of O_2 = Eutrophication.

Overuse of nitrogen fertiliser can have nasty environmental consequences.

Additional resource: **xtremepapers.com**

#48 Summary of plant nutrition



- Photosynthesis takes place in chloroplasts in the leaves of plants.
- The word equation for photosynthesis is:

Word equation

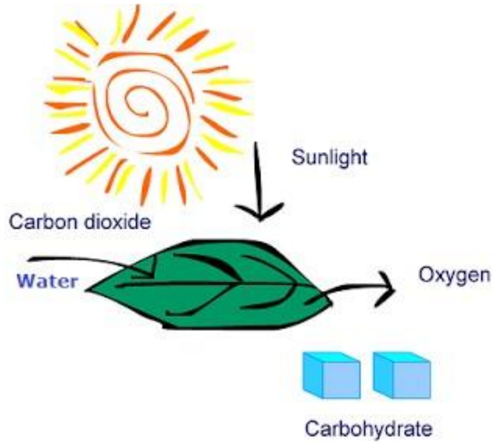
$$\text{Carbon dioxide} + \text{Water} \xrightarrow[\text{Chlorophyll}]{\text{Light}} \text{Glucose} + \text{Oxygen}$$

- The balanced equation is:

Symbol equation

$$6CO_2 + 6H_2O \xrightarrow[\text{Chlorophyll}]{\text{Light}} C_6H_{12}O_6 + 6O_2$$

- Chlorophyll traps energy from light. In photosynthesis, this energy is converted to chemical energy in carbohydrates.



- Photosynthesis takes place in the cells of the mesophyll layer, especially the palisade mesophyll. Leaves are thin and have a large surface area, to speed up the supply of carbon dioxide to the palisade cells and to maximise the amount of sunlight that hits the leaf and can be absorbed by chlorophyll. Stomata and air spaces allow carbon dioxide to diffuse quickly from the air to the chloroplasts. Xylem vessels bring water, and phloem tubes take away the products of photosynthesis.

- Some of the glucose that is made is used in respiration, to provide energy to the plant cells. Some is stored as starch. Some is used to make cellulose for cell walls. Some is transported around the plant in the form of sucrose, in the phloem tubes. Some is combined with nitrate or ammonium ions to make proteins. Some is used to make other substances such as fats. With the addition of magnesium ions, chlorophyll can be made.

- When testing a leaf for starch, it must first be boiled to break down cell membranes and allow iodine solution to make contact with any starch inside the cells. Hot alcohol will remove chlorophyll from the leaf, making it easier to see any colour changes.
- Plants need light and carbon dioxide for photosynthesis.

- If either light or carbon dioxide are in short supply, they limit the rate of photosynthesis and are said to be limiting factors. The rate of photosynthesis is also affected by temperature.