Cambridge (CIE) IGCSE Biology

Your notes

Photosynthesis & Leaf Structure

Contents

Photosynthesis

- Green plants make the carbohydrate **glucose** from the raw materials **carbon dioxide** and **water**
- At the same time **oxygen** is made and released as a waste product
- The reaction requires **energy** which is obtained by the pigment **chlorophyll** trapping light from the Sun
- So photosynthesis can be defined as **the process by which plants manufacture carbohydrates from raw materials using energy from light**

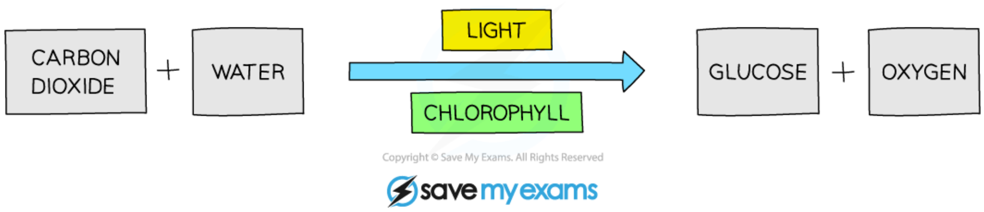
Examiner Tips and Tricks

If asked for the raw materials required for photosynthesis, the answer is **carbon dioxide and water.**

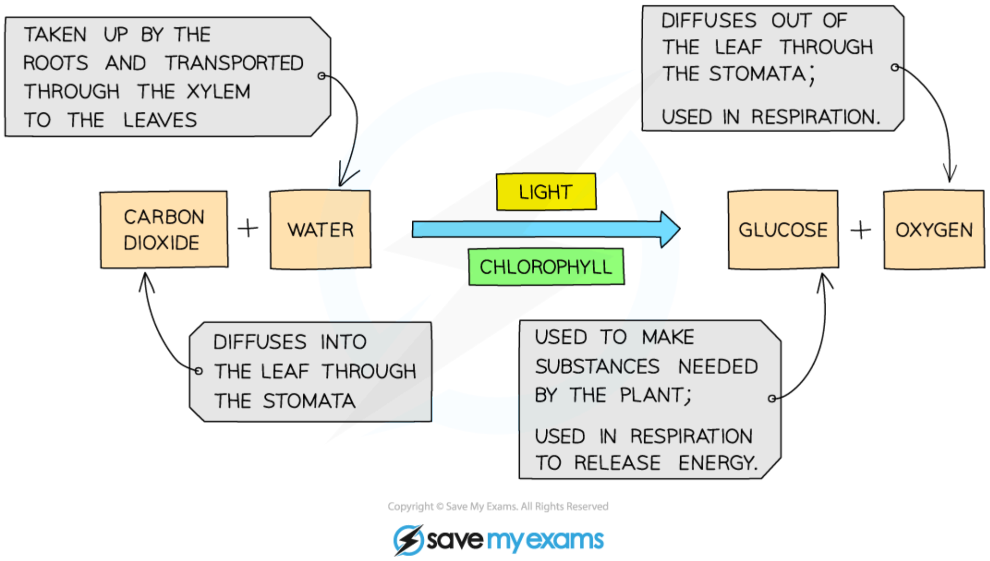
Although required for the reaction to take place, light energy is not a substance and therefore cannot be a raw material.

Photosynthesis Word Equation

- The photosynthesis word equation can be summarised as follows:



Photosynthesis word equation



How plants get the materials they need

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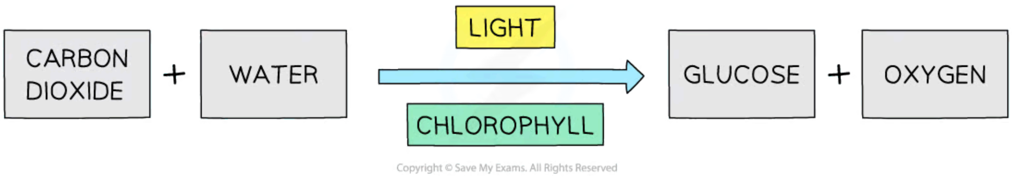
Chlorophyll

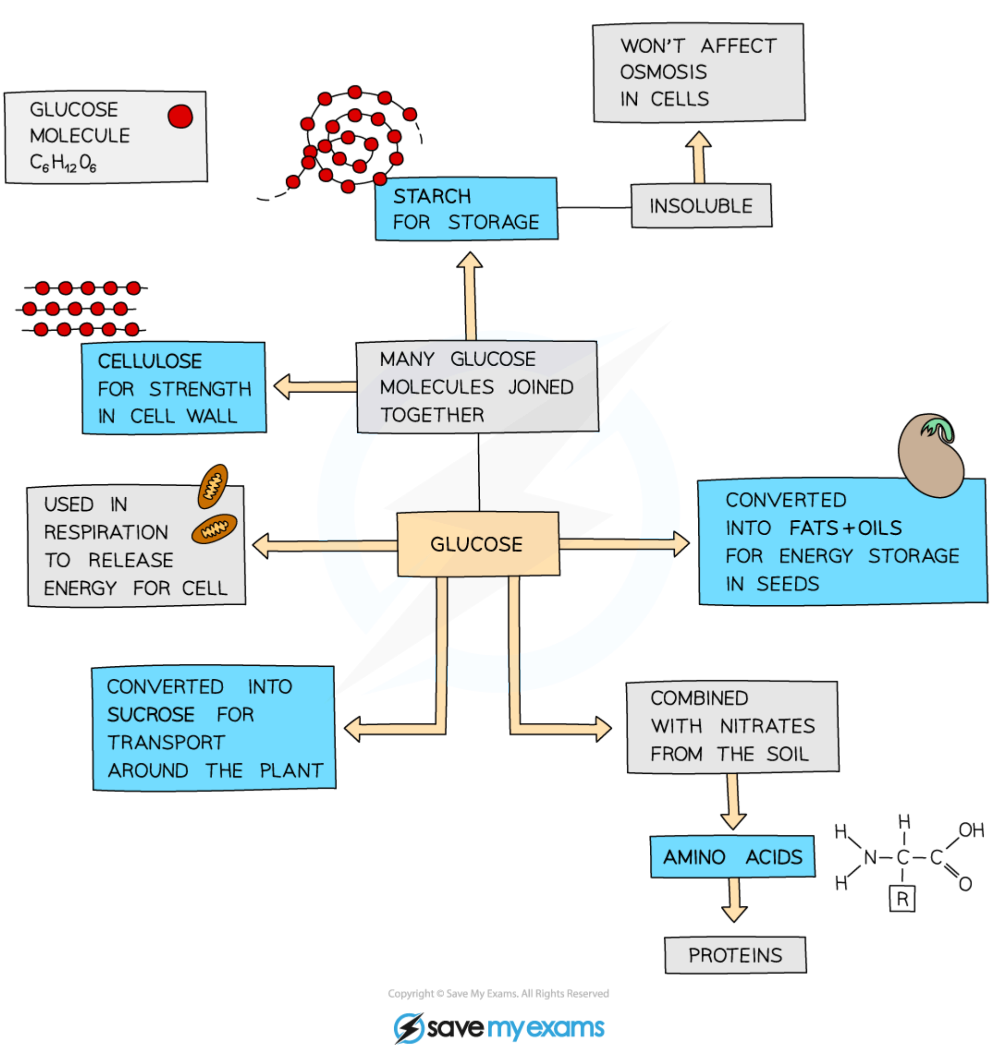
- Chlorophyll is a **green pigment** that is found in **chloroplasts** within plant cells
  - It reflects green light, giving plants their characteristic green colour
- Chlorophyll absorbs light energy; its role is to transfer energy from **light** into energy in **chemicals**, for the synthesis of carbohydrates, such as glucose
  - Photosynthesis will not occur in the absence of chlorophyll



Use & Storage of Carbohydrates

How are the products of photosynthesis used?

- The carbohydrates produced by plants during photosynthesis can be used in the following ways:
  - Converted into **starch** molecules which act as an effective **energy store**
  - Converted into **cellulose** to build **cell walls**
  - Glucose can be used in **respiration** to provide energy
  - Converted to sucrose for **transport** in the phloem
  - As **nectar** to attract insects for pollination
- Plants can also convert the carbohydrates made into **lipids** for an energy source in seeds and into **amino acids** (used to make proteins) when combined with nitrogen and other mineral ions absorbed by roots



The fate of glucose

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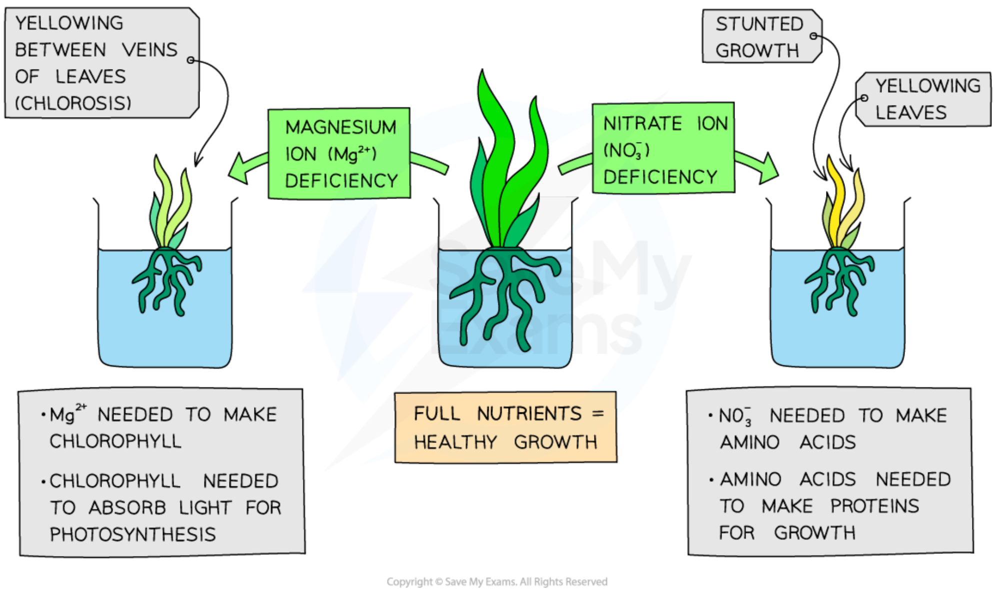
Minerals in Plants

- Photosynthesis produces carbohydrates, but plants contain many other types of biological molecule; such as proteins, lipids and nucleic acid (DNA)
- As plants do not eat, they need to **make these substances themselves**
- Carbohydrates contain the elements carbon, hydrogen and oxygen but proteins, for example, contain **nitrogen** as well (and certain amino acids contain other elements too)
- Other chemicals in plants contain different elements as well, for example chlorophyll contains **magnesium** and **nitrogen**
- This means that without a source of these elements, plants cannot photosynthesise or grow properly
- Plants obtain these elements in the form of **mineral ions actively absorbed from the soil by root hair cells**
- 'Mineral' is a term used to describe any naturally occurring inorganic substance



Mineral deficiencies in plants

Mineral Deficiencies Table

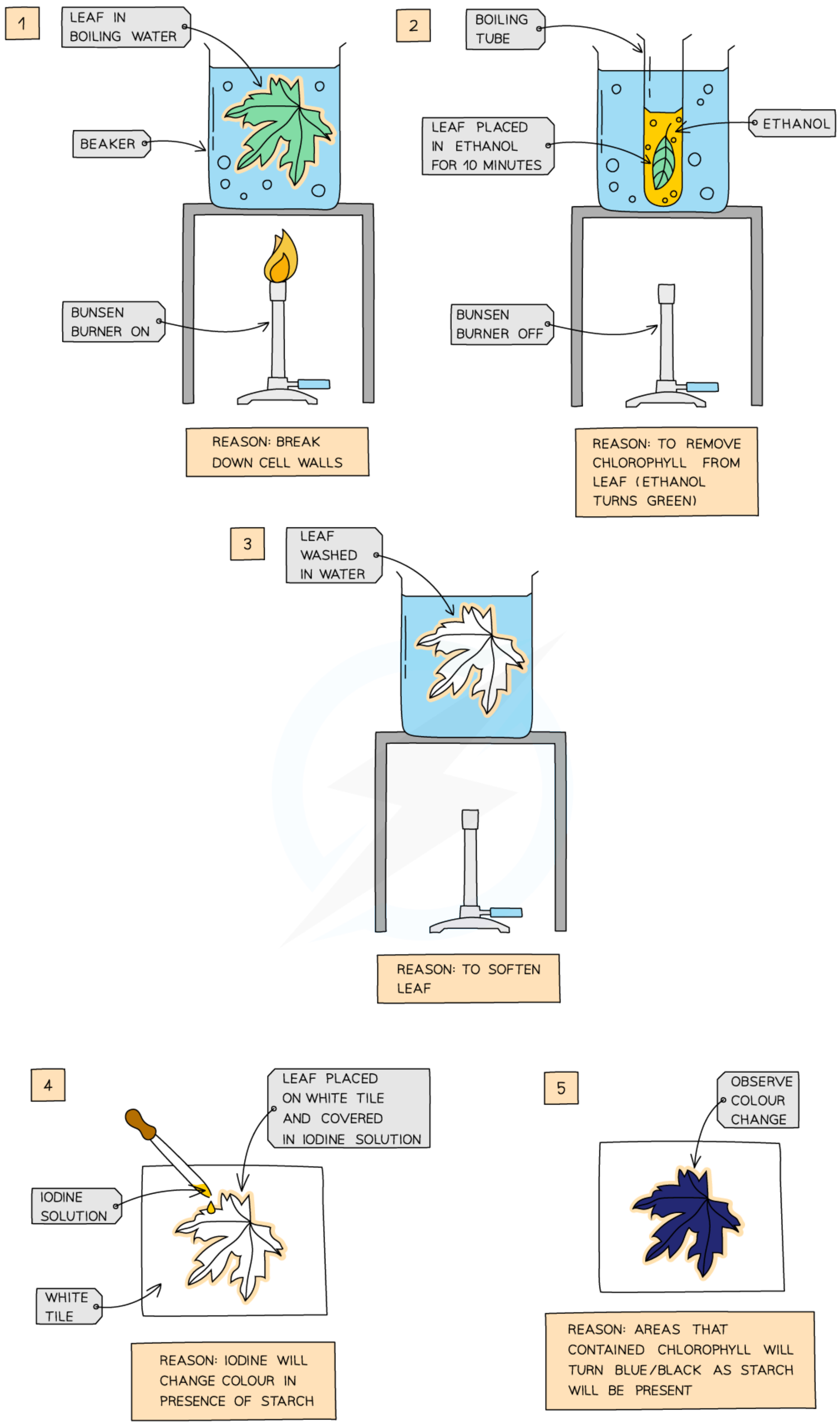
Your notes

MINERAL ION	FUNCTION	DEFICIENCY
MAGNESIUM	MAGNESIUM IS NEEDED TO MAKE **CHLOROPHYLL**	CAUSES YELLOWING BETWEEN THE VEINS OF LEAVES (**CHLOROSIS**)
NITRATE	NITRATES ARE A SOURCE OF NITROGEN NEEDED TO MAKE **AMINO ACIDS** (TO BUILD PROTEINS)	CAUSES **STUNTED GROWTH** AND **YELLOWING OF LEAVES**

Investigating the Need for Chlorophyll, Light & Carbon Dioxide

Investigating the Need for Chlorophyll

- Although plants make glucose in photosynthesis, **leaves cannot be tested for its presence** as the glucose is quickly used, converted into other substances and transported or stored as starch.
- Starch is stored in chloroplasts where photosynthesis occurs so **testing a leaf for starch** is a reliable indicator of which parts of the leaf are photosynthesising.
- Leaves can be tested for starch using the following procedure:
  - A leaf is dropped in **boiling water** to **kill the cells and break down the cell membranes**
  - The leaf is left for 5-10 minutes in hot **ethanol** in a boiling tube. This **removes the chlorophyll** so colour changes from iodine can be seen more clearly
  - The leaf is dipped in boiling water to soften it
  - The leaf is spread out on a white tile and covered with **iodine solution**
  - In a green leaf, the entire leaf will turn **blue-black** as photosynthesis is occurring in all areas of the leaf
  - This method can also be used to test whether chlorophyll is needed for photosynthesis by using a **variegated** leaf (one that is partially green and partially white)
  - The white areas of the leaf contain no chlorophyll and when the leaf is tested **only the areas that contain chlorophyll stain blue-black**
  - The areas that had no chlorophyll remain orange-brown as **no photosynthesis is occurring here and so no starch is stored**


1
LEAF IN BOILING WATER
BEAKER
BUNSEN BURNER ON
REASON: BREAK DOWN CELL WALLS
2
BOILING TUBE
LEAF PLACED IN ETHANOL FOR 10 MINUTES
ETHANOL
BUNSEN BURNER OFF
REASON: TO REMOVE CHLOROPHYLL FROM LEAF (ETHANOL TURNS GREEN)
3
LEAF WASHED IN WATER
REASON: TO SOFTEN LEAF
4
LEAF PLACED ON WHITE TILE AND COVERED IN IODINE SOLUTION
IODINE SOLUTION
WHITE TILE
REASON: IODINE WILL CHANGE COLOUR IN PRESENCE OF STARCH
5
OBSERVE COLOUR CHANGE
REASON: AREAS THAT CONTAINED CHLOROPHYLL WILL TURN BLUE/BLACK AS STARCH WILL BE PRESENT

Your notes

Testing a variegated leaf for starch

- Care must be taken when carrying out this practical as **ethanol is extremely flammable**, so at that stage of the experiment the Bunsen burner should be turned off.
- The safest way to heat the ethanol is in an electric water bath rather than using a beaker over a Bunsen burner with an open flame

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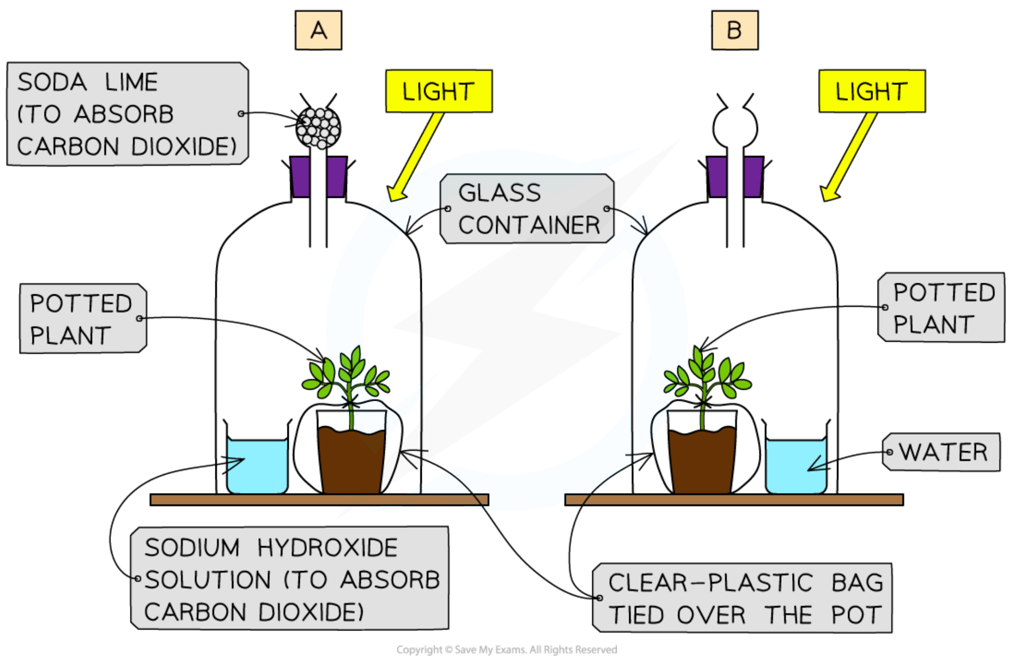
Investigating the Need for Light

- The same procedure as above can be used to investigate if light is needed for photosynthesis
- Before starting the experiment the plant needs to be **destarched** by placing in a dark cupboard for 24 hours
- This ensures that **any starch already present in the leaves will be used up** and will not affect the results of the experiment
- Following destarching, a leaf of the plant can be **partially covered with aluminium foil** and the plant placed in sunlight for a day
- The leaf can then be removed and tested for starch using iodine
- The area of the leaf that was covered with aluminium foil will **remain orange-brown** as it did not receive any sunlight and could not photosynthesise, while the area exposed to sunlight will turn **blue-black**
- This proves that light is necessary for photosynthesis and the production of starch

Investigating the Need for Carbon Dioxide

- Destarch two plants by placing in the dark for a prolonged period of time
- Place one plant in a bell jar which contains a beaker of **sodium hydroxide** (which will **absorb carbon dioxide** from the surrounding air)
- Place the other plant in a bell jar which contains a beaker of water (control experiment), which will **not absorb carbon dioxide** from the surrounding air
- Place both plants in bright light for several hours
- Test both plants for starch using iodine
- The leaf from the plant placed near sodium hydroxide will **remain orange-brown** as it could not photosynthesise due to lack of carbon dioxide
- The leaf from the plant placed near water should turn blue-black as it had all necessary requirements for photosynthesis



An example setup for an experiment to test whether carbon dioxide is necessary for photosynthesis in plants.

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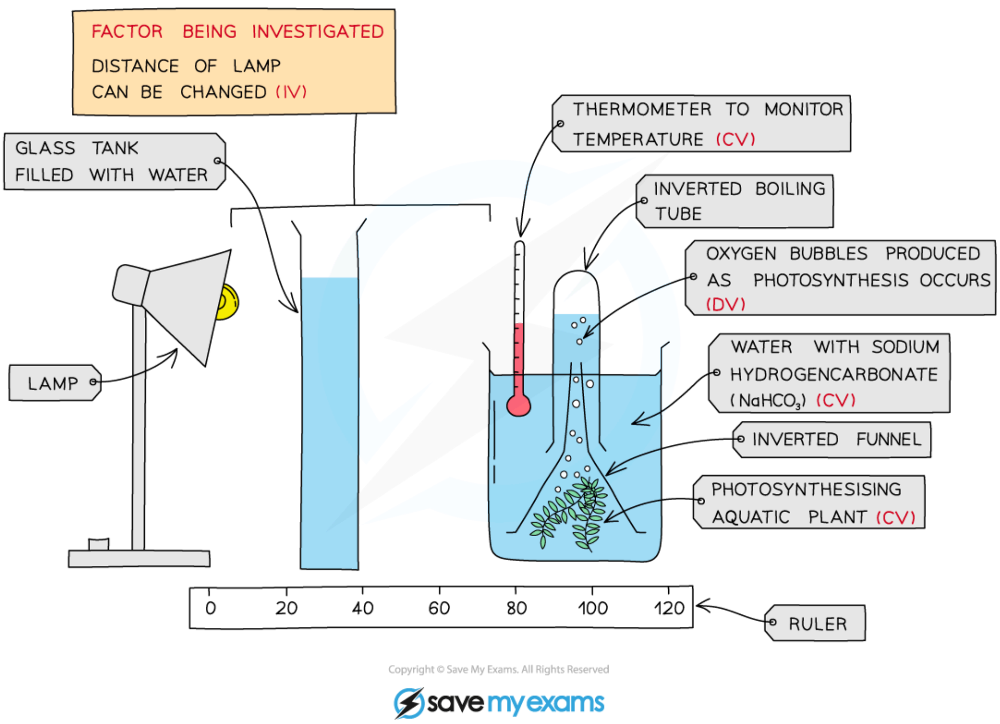
Investigating the Rate of Photosynthesis

- The plants usually used are ***Elodea*** or ***Cabomba*** - types of pondweed
- As photosynthesis occurs, oxygen gas produced is released
- As the plant is in water, the oxygen released can be seen as **bubbles** leaving the cut end of the pondweed
- The number of **bubbles produced over a minute** can be counted to record the rate
- The more bubbles produced per minute, the faster the rate of photosynthesis
- A more accurate version of this experiment is to collect the oxygen released in a test tube inverted over the top of the pondweed over a longer period of time and then measure the **volume of oxygen** collected
- This practical can be used in the following ways:

Investigating the effect of changing light intensity

- This can be done by moving a lamp different distances away from the beaker containing the pondweed

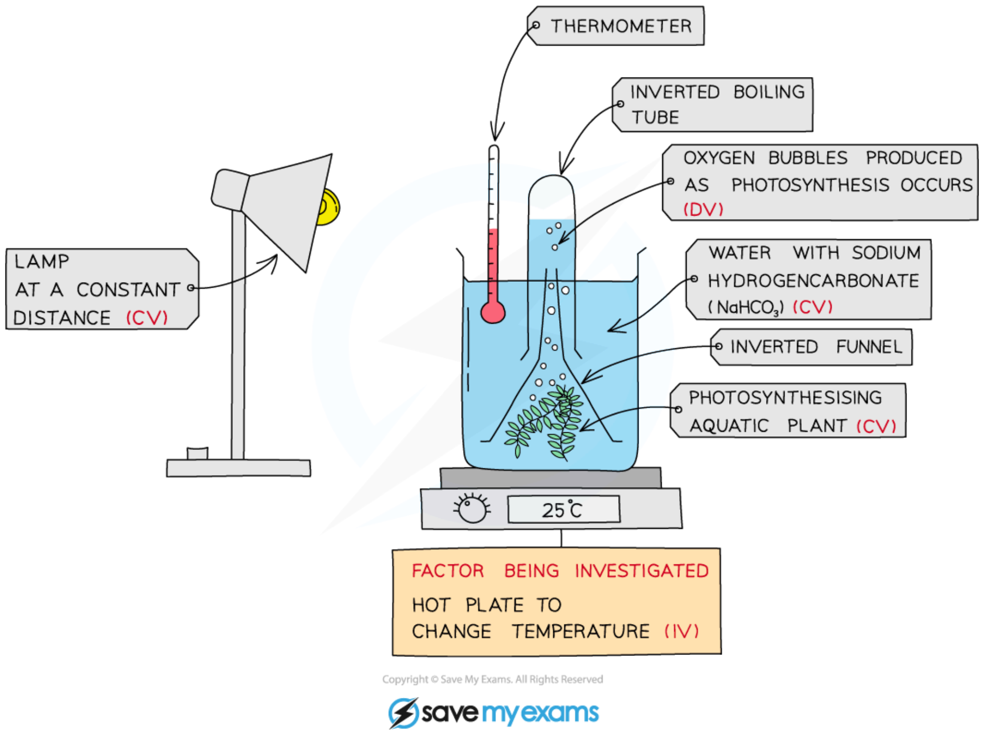


Investigating the effect of changing light intensity on the rate of photosynthesis

Your notes

Investigating the effect of changing temperature

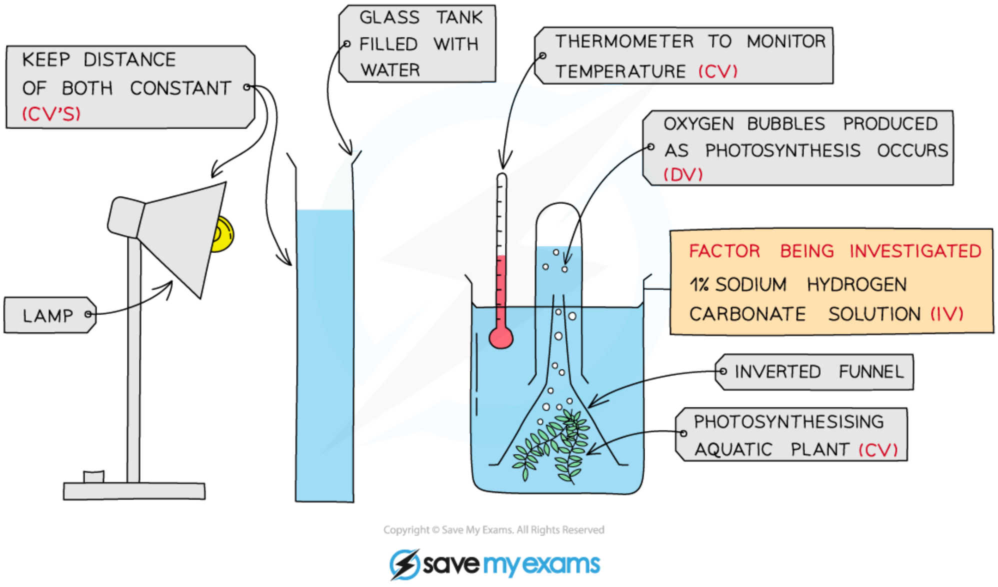
- This can be done by changing the temperature of the water in the beaker



Investigating the effect of changing temperature on the rate of photosynthesis

Investigating the effect of changing carbon dioxide concentration

- This can be done by dissolving different amounts of sodium hydrogen carbonate in the water in the beaker



Investigating the effect of changing carbon dioxide concentration on the rate of photosynthesis

- Care must be taken when investigating a condition to **keep all other variables constant** in order to ensure a **fair test**
- For example, when investigating changing light intensity, a **glass tank** should be placed in between the lamp and the beaker to **absorb heat** from the lamp and so avoid changing the temperature of the water as well as the light intensity

Examiner Tips and Tricks

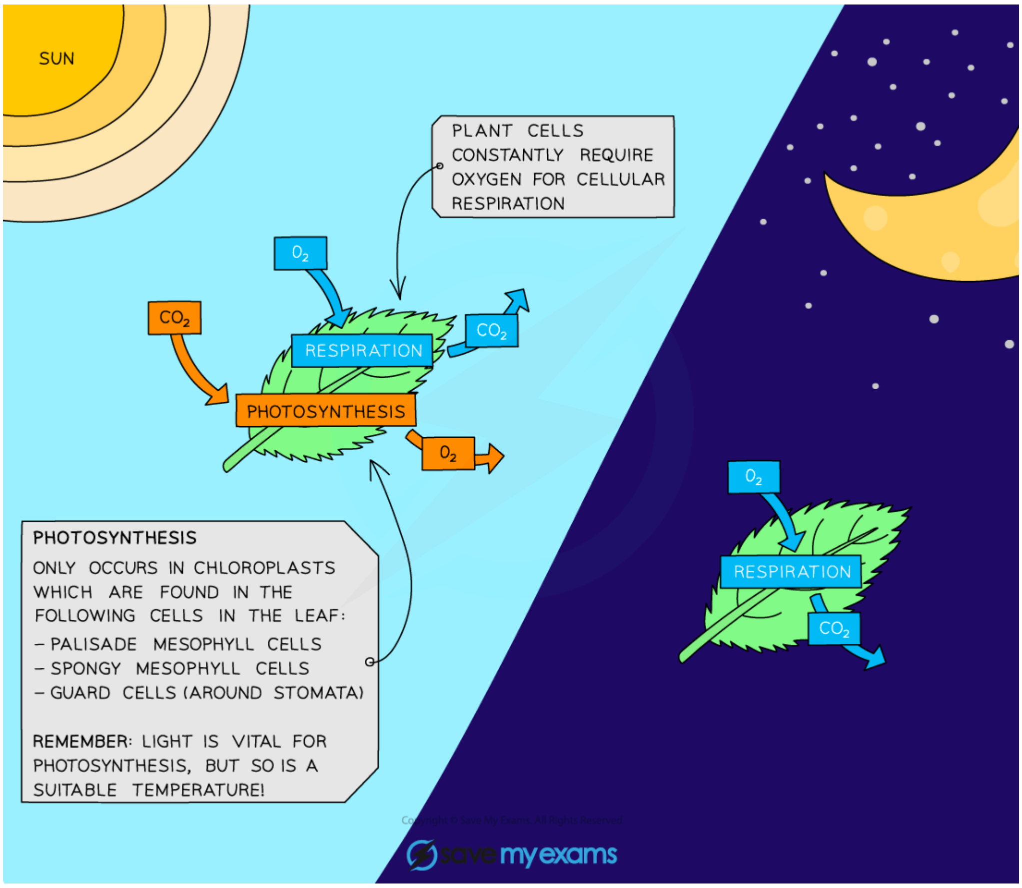
Alternative ways of measuring the gas (oxygen) given off in these experiments would be to:

- measure the volume of gas produced using an inverted measuring cylinder with graduations filled with water that readings can be taken from as the water is displaced by the gas
- or by using a syringe attached by a delivery tube to the funnel

Your notes

Investigating Gas Exchange

- Plants are **respiring all the time** and so plant cells are **taking in oxygen and releasing carbon dioxide** as a result of aerobic respiration
- Plants also **photosynthesise during daylight** hours, for which they need to **take in carbon dioxide and release the oxygen** made in photosynthesis
- At night, plants do not photosynthesise but they continue to respire, meaning they **take in oxygen and give out carbon dioxide**



Photosynthesis and respiration in plants

- During the day, especially when the sun is bright, **plants are photosynthesising at a faster rate than they are respiring**, so there is a **net intake of carbon dioxide and a net output of oxygen**
- We can investigate the effect of light on the **net gas exchange** in an aquatic plant using a **pH indicator** such as **hydrogencarbonate indicator**
- This is possible because carbon dioxide is an **acidic gas** when dissolved in water
- Hydrogencarbonate indicator shows the **carbon dioxide concentration in solution**

- The table below shows the **colour** that the indicator turns at **different levels of carbon dioxide concentration**

CONCENTRATION OF CARBON DIOXIDE	COLOUR OF HYDROGEN CARBON INDICATOR	CONDITIONS IN PLANT
HIGHEST	YELLOW	MORE RESPIRATION > PHOTOSYNTHESIS – LOWER pH (MORE ACID)
HIGHER	ORANGE	
ATMOSPHERIC LEVEL	RED	PHOTOSYNTHESIS = RESPIRATION
LOWER	MAGENTA	MORE PHOTOSYNTHESIS > RESPIRATION – HIGHER pH (MORE ALKALINE)
LOWEST	PURPLE	

- Several leaves from the same plant are placed in stoppered boiling tubes containing some **hydrogencarbonate indicator**
- The effect of light can then be investigated over a period of a few hours
- Results from a typical experiment are shown in the table below:

TUBE	CONTENTS	CONDITIONS	INDICATOR TURNS	CONCLUSION
A	LEAF	LIGHT	PURPLE	THERE IS A NET INTAKE OF CARBON DIOXIDE BY A LEAF IN LIGHT
B	LEAF	DARK	YELLOW	THERE IS A NET INTAKE OF OXYGEN BY A LEAF IN THE DARK
C	NO LEAF	LIGHT	RED	THIS IS THE CONTROL – THE TWO OTHER TUBES CAN BE COMPARED WITH IT

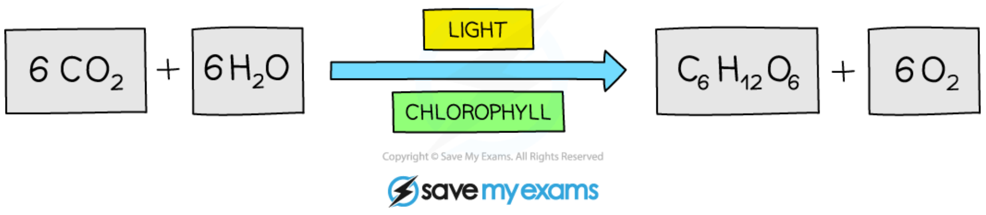
Your notes

Your notes

Balanced Photosynthesis Chemical Equation: Extended

Extended Tier Only

- The balanced chemical equation for photosynthesis is:



Balanced chemical equation for photosynthesis

- The **light energy** is converted into **chemical energy** in the **bonds** holding the atoms in the glucose molecules together

Examiner Tips and Tricks

The photosynthesis equation is the exact reverse of the aerobic respiration equation so if you have learned one you also know the other one! You will usually get more marks for providing **the balanced chemical equation** than the word equation.

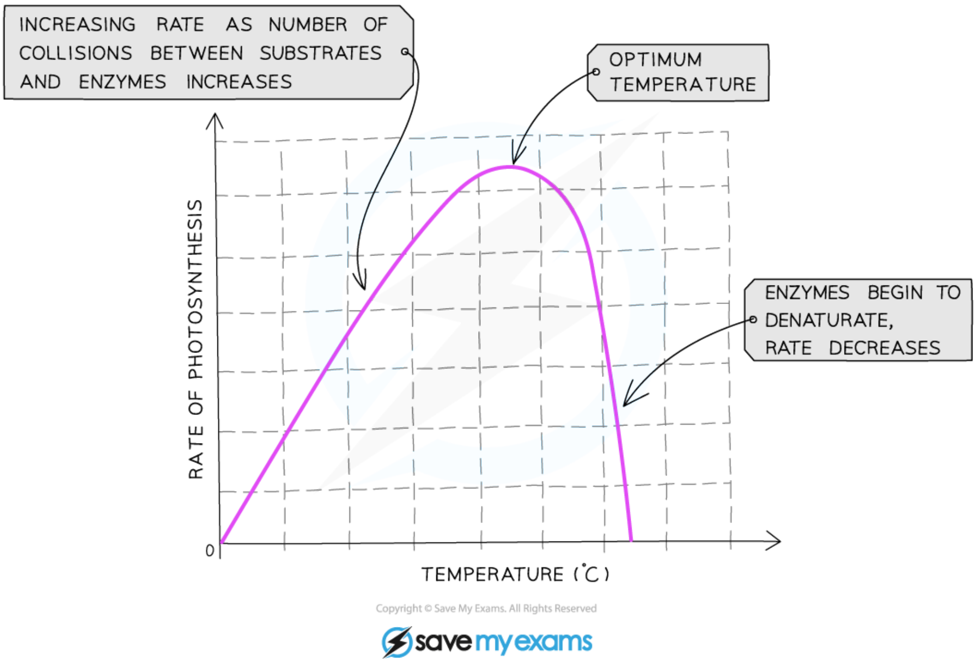
Limiting Factors: Extended

Extended Tier Only

- If a plant is given unlimited sunlight, carbon dioxide and water and is at a warm temperature, the limit on the rate (speed) at which it can photosynthesise is its own ability to absorb these materials and make them react
- However, most often plants do not have unlimited supplies of their raw materials so their rate of photosynthesis is **limited** by **whatever factor is the lowest at that time**
- **So a limiting factor can be defined as something present in the environment in such short supply that it restricts life processes**
- There are **three** main factors which limit the rate of photosynthesis:
  - **Temperature**
  - **Light intensity**
  - **Carbon dioxide concentration**
- Although water is necessary for photosynthesis, it is **not considered a limiting factor** as the amount needed is relatively small compared to the amount of water transpired from a plant so there is hardly ever a situation where there is not enough water for photosynthesis

Temperature

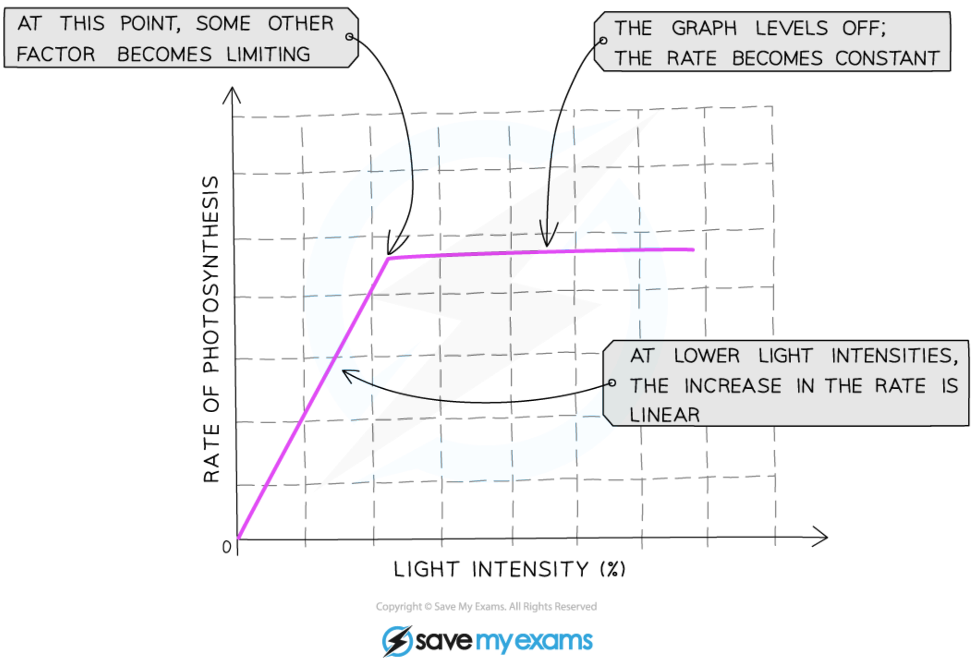
- As temperature increases the rate of photosynthesis increases as the reaction is **controlled by enzymes**
- However, as the reaction is controlled by enzymes, this trend only continues up to a certain temperature beyond which the enzymes begin to **denature** and the rate of reaction **decreases**



The effect of temperature on the rate of photosynthesis

Light intensity

- The **more light** a plant receives, the **faster the rate** of photosynthesis
- This trend will continue until some other factor required for photosynthesis prevents the rate from increasing further because it is now in short supply



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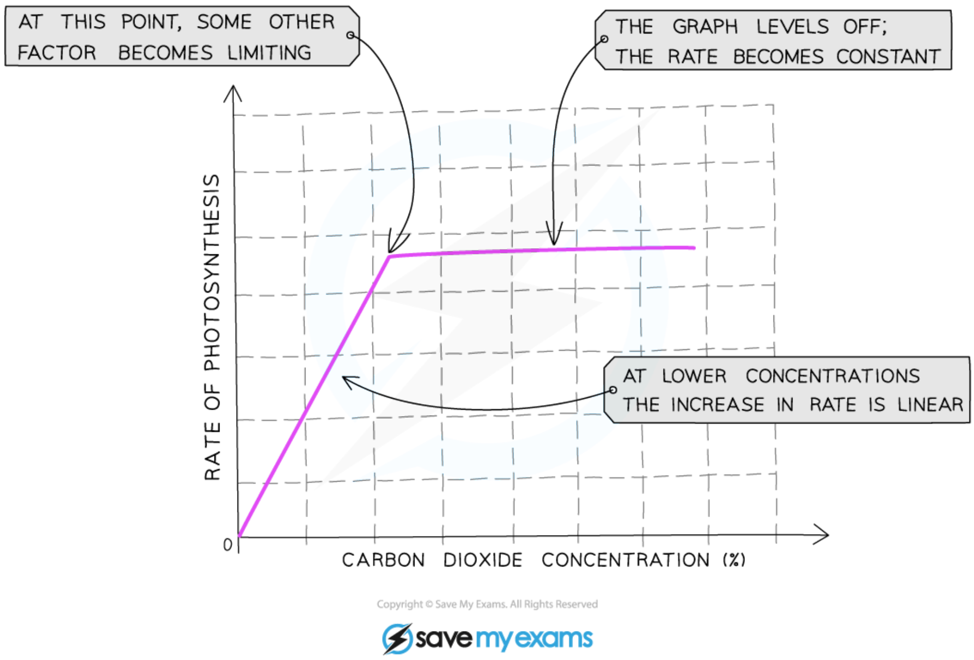
The effect of light intensity on the rate of photosynthesis

- At low light intensities, increasing the intensity will initially increase the rate of photosynthesis. At a certain point, increasing the light intensity stops increasing the rate. The rate becomes constant regardless of how much light intensity increases as something else is limiting the rate
- The factors which could be limiting the rate when the line on the graph is horizontal include **temperature not being high enough** or **not enough carbon dioxide.**

Carbon dioxide concentration

- Carbon dioxide is one of the raw materials required for photosynthesis
- This means the **more carbon dioxide** that is present, the **faster the reaction** can occur
- This trend will continue until some other factor required for photosynthesis prevents the rate from increasing further because it is now in short supply



The effect of carbon dioxide concentration on the rate of photosynthesis

- The factors which could be limiting the rate when the line on the graph is horizontal include **temperature not being high enough** or **not enough light**

Examiner Tips and Tricks

Interpreting graphs of limiting factors can be confusing for many students, but it's quite simple. In the section of the graph where the rate is increasing (the line is going up), the limiting factor is whatever the label on the x axis (the bottom axis) of the graph

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is. In the section of the graph where the rate is not increasing (the line is horizontal), the limiting factor will be something other than what is on the x axis – choose from temperature, light intensity or carbon dioxide concentration.

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Leaf Structure & Adaptations for Photosynthesis

Leaf structure

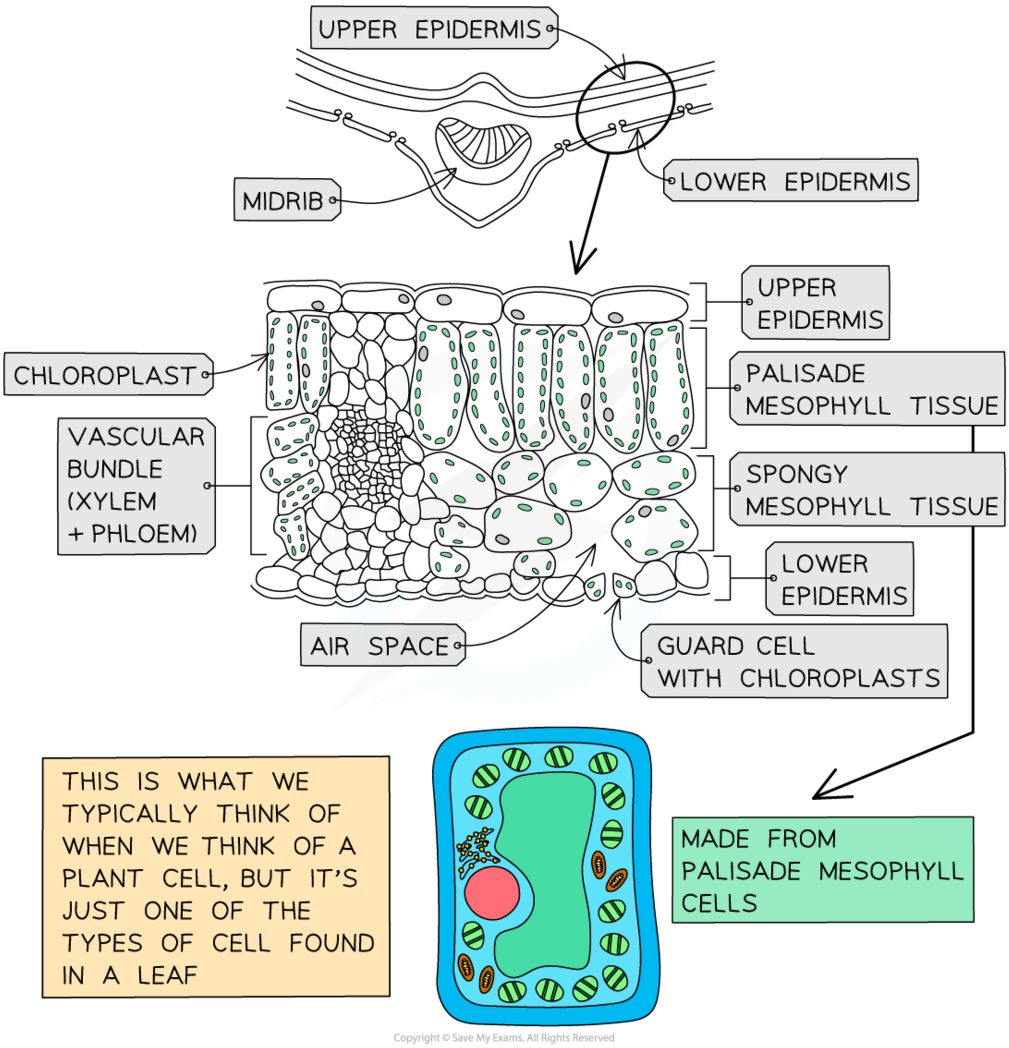
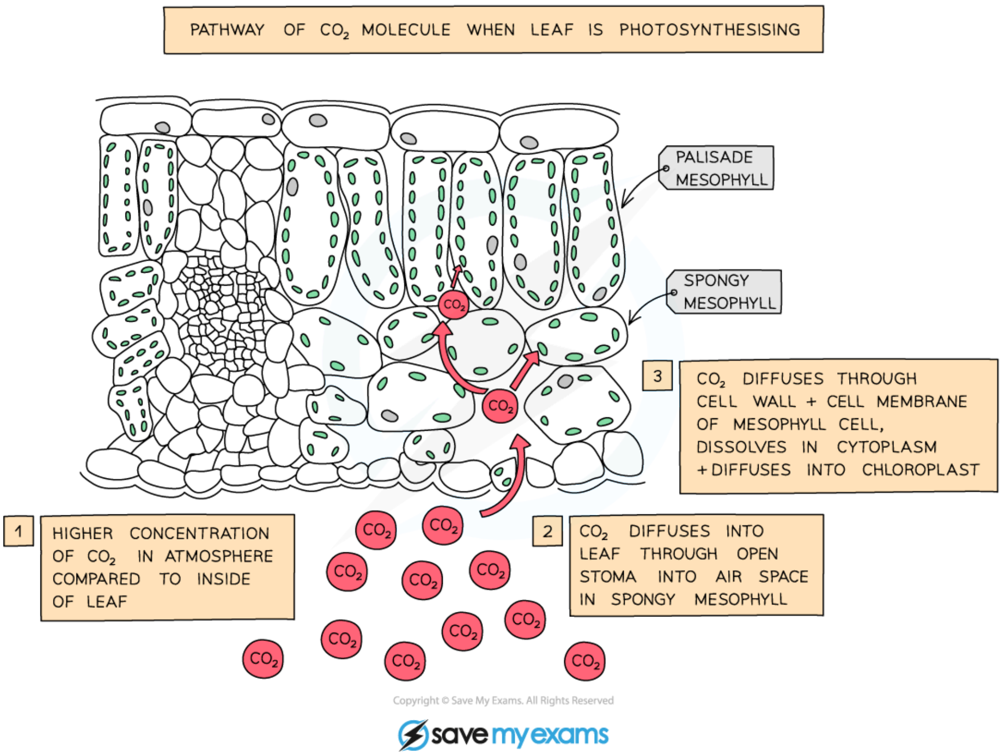


Diagram showing the cross-section of a leaf



How photosynthesising cells obtain carbon dioxide

- Pathway of carbon dioxide from the atmosphere to chloroplasts by diffusion:

atmosphere → air spaces around spongy mesophyll tissue → leaf mesophyll cells → chloroplast

Leaf Structure Table

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STRUCTURE	DESCRIPTION
WAX CUTICLE	PROTECTIVE LAYER ON TOP OF THE LEAF, PREVENTS WATER FROM EVAPORATING
UPPER EPIDERMIS	THIN AND TRANSPARENT TO ALLOW LIGHT TO ENTER PALISADE MESOPHYLL LAYER UNDERNEATH IT
PALISADE MESOPHYLL	COLUMN SHAPED CELLS TIGHTLY PACKED WITH CHLOROPLASTS TO ABSORB MORE LIGHT, MAXIMISING PHOTOSYNTHESIS
SPONGY MESOPHYLL	CONTAINS INTERNAL AIR SPACES THAT INCREASES THE SURFACE AREA TO VOLUME RATIO FOR THE DIFFUSION OF GASES (MAINLY CARBON DIOXIDE)
LOWER EPIDERMIS	CONTAINS GUARD CELLS AND STOMATA
GUARD CELL	ABSORBS AND LOSES WATER TO OPEN AND CLOSE THE STOMATA TO ALLOW CARBON DIOXIDE TO DIFFUSE IN, OXYGEN TO DIFFUSE OUT
STOMATA	WHERE GAS EXCHANGE TAKES PLACE; OPENS DURING THE DAY, CLOSES DURING THE NIGHT. EVAPORATION OF WATER ALSO TAKES PLACE FROM HERE. IN MOST PLANTS, FOUND IN MUCH GREATER CONCENTRATION ON THE UNDERSIDE OF THE LEAF TO REDUCE WATER LOSS
VASCULAR BUNDLE	CONTAINS XYLEM AND PHLOEM TO TRANSPORT SUBSTANCES TO AND FROM THE LEAF
XYLEM	TRANSPORTS WATER INTO THE LEAF FOR MESOPHYLL CELLS TO USE IN PHOTOSYNTHESIS AND FOR TRANSPIRATION FROM STOMATA
PHLOEM	TRANSPORTS SUCROSE AND AMINO ACIDS AROUND THE PLANT

Adaptations of Leaf Structure for Photosynthesis Table

FEATURE	ADAPTATION
LARGE SURFACE AREA (LEAF)	INCREASES SURFACE AREA FOR THE DIFFUSION OF CARBON DIOXIDE AND ABSORPTION OF LIGHT FOR PHOTOSYNTHESIS
THIN	ALLOWS CARBON DIOXIDE TO DIFFUSE TO PALISADE MESOPHYLL CELLS QUICKLY
CHLOROPHYLL	ABSORBS LIGHT ENERGY SO THAT PHOTOSYNTHESIS CAN TAKE PLACE
NETWORK OF VEINS	ALLOWS THE TRANSPORT OF WATER TO THE CELLS OF THE LEAF AND CARBOHYDRATES FROM THE LEAF FOR PHOTOSYNTHESIS (WATER FOR PHOTOSYNTHESIS, CARBOHYDRATES AS A PRODUCT OF PHOTOSYNTHESIS)
STOMATA	ALLOWS CARBON DIOXIDE TO DIFFUSE INTO THE LEAF AND OXYGEN TO DIFFUSE OUT
EPIDERMIS IS THIN AND TRANSPARENT	ALLOWS MORE LIGHT TO REACH THE PALISADE CELLS
THIN CUTICLE MADE OF WAX	TO PROTECT THE LEAF WITHOUT BLOCKING SUNLIGHT
PALISADE CELL LAYER AT TOP OF LEAF	MAXIMISES THE ABSORPTION OF LIGHT AS IT WILL HIT CHLOROPLASTS IN THE CELLS DIRECTLY
SPONGY LAYER	AIR SPACES ALLOW CARBON DIOXIDE TO DIFFUSE THROUGH THE LEAF, INCREASING THE SURFACE AREA
VASCULAR BUNDLES	THICK CELL WALLS OF THE TISSUE IN THE BUNDLES HELP TO SUPPORT THE STEM AND LEAF

Your notes

Identifying Leaf Structures in a Dicotyledonous Plant

- You will be expected to identify the following structures in the leaf of a dicotyledonous plant:
    - Chloroplasts
    - Cuticle
    - Guard cells
    - Stomata
    - Upper and lower epidermis
    - Palisade mesophyll
    - Spongy mesophyll
    - Air spaces
    - Vascular bundles (xylem and phloem)

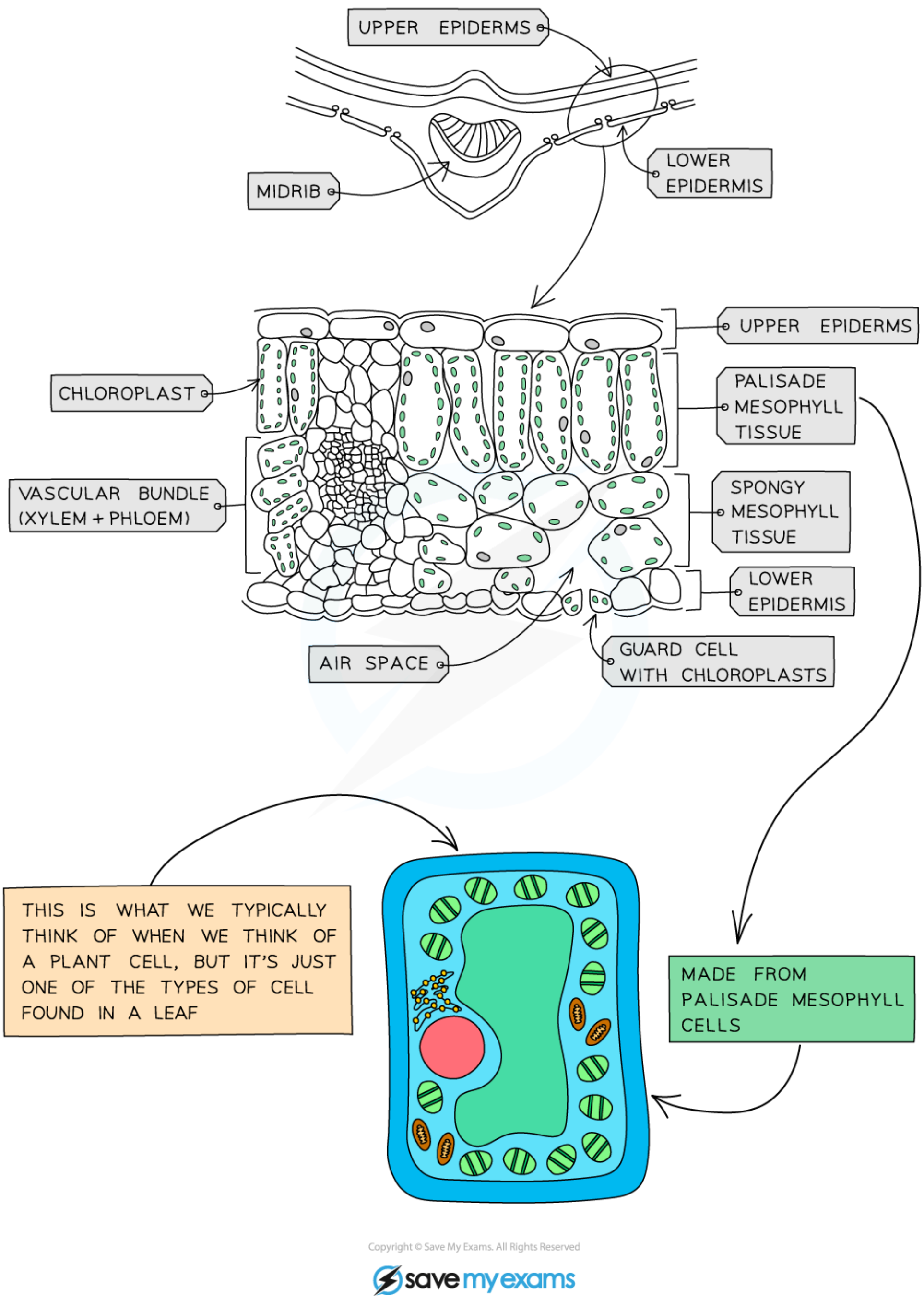
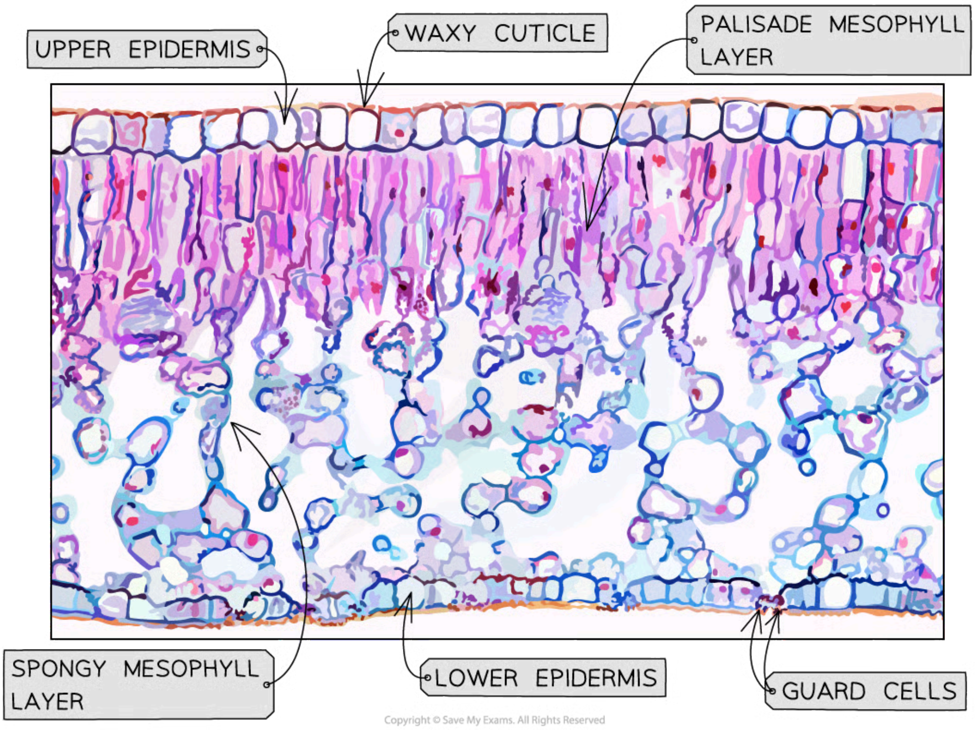


Diagram showing the cross-section of a leaf



An electron micrograph of a leaf

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